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Advanced LIGO, BSC-ISI, Stage 1 analysis

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Advanced LIGO Project

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Introduction

This document describes the successive steps of analysis that lead to the current stage 1 design.

The first section shows the FEA analysis done to optimize the close out plate stiffness.
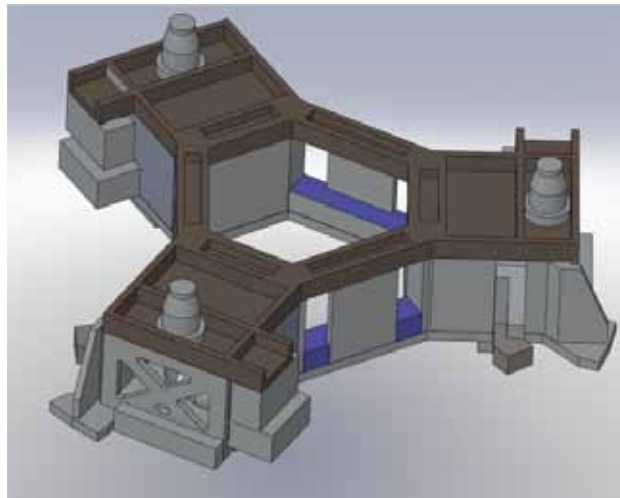
The second section analysis the influence of stiffeners.

The third section is shows the influence of the ballast mass on the structure modes.

The fourth section is a mass budget and center of masses table.

1   Stage 1 close out plate stiffness optimization

Dummy mass are used to simulate the embedded mass of sensors, actuators, trim masses and ballasts:

All contacts are modeled perfectly bonded. As a consequence the frequencies obtained will over estimate reality. These values must only be used to compare one design to another.
Solid elements called SOLID92 have been used for the meshes. The same average element size has been used for the successive studies.

Note:

- to simplify the modeling, the ballast have been modeled in aluminum (this allows to merge all the volumes more easily). To compensate for this lower mass it has been modeled larger. However the model stays lighter than reality: 31Lbs vs 75Lbs.

- all other components (sensors, actuators, trim masses) have masses very close to reality.

- in the last section, a final calculation is done using the actual mass material and volumes of the ballast. Contact elements have been used to connect the ballast to the base plate.
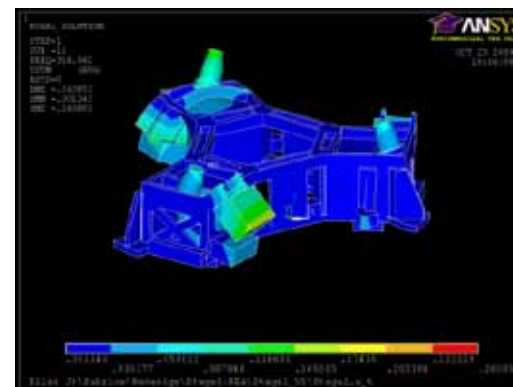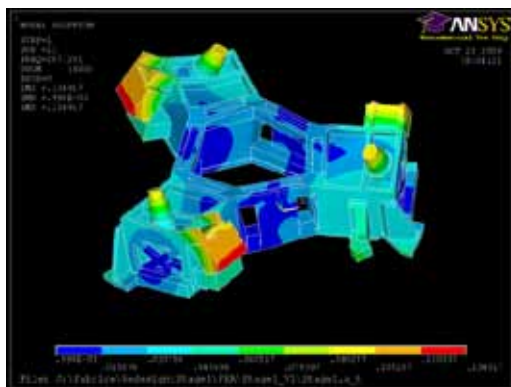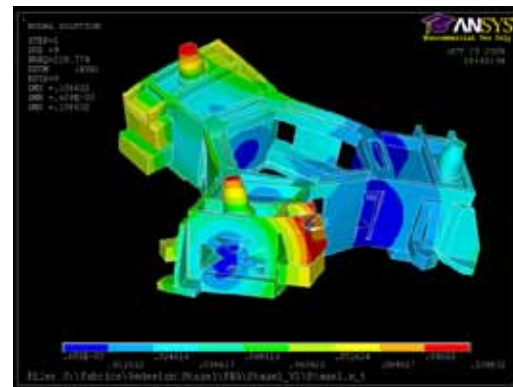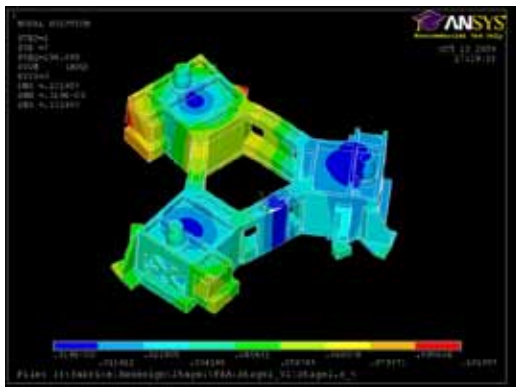
1.1   Initial version (V1)
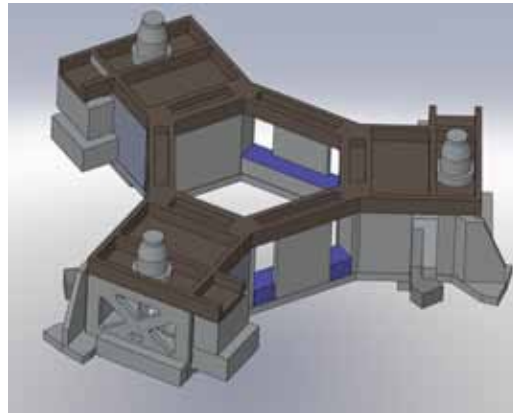
V1, 237 Lbs

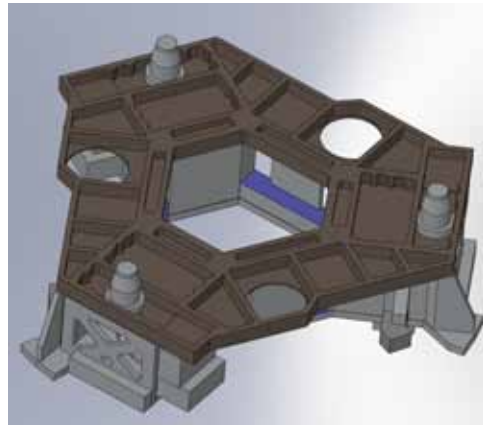|	Initial: V1, 237 Lbs
1	195
2	195
3	229
4	229
5	287
6	319
7	319
8	335
9	352

Initial version.
First 2 modes are in plane bending modes.
Modes 3, 4 and 5 are torsion modes.
Mode 6 is a local mode of the actuator

1.2   Version 2

V2, 353 Lbs

	V1, 237 Lbs	V2, 353 Lbs
1	195	214
2	195	214
3	229	269
4	229	298
5	287	299
6	319	321
7	319	322
8	335	324
9	352	361

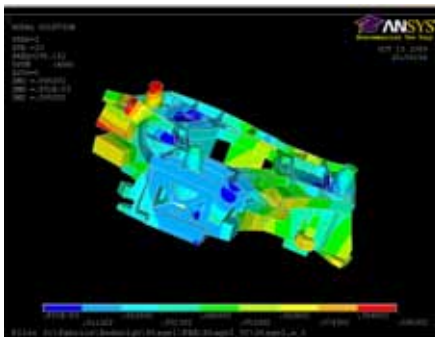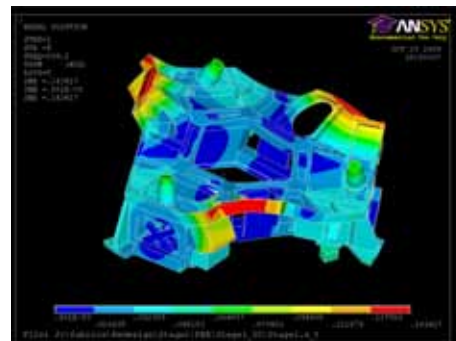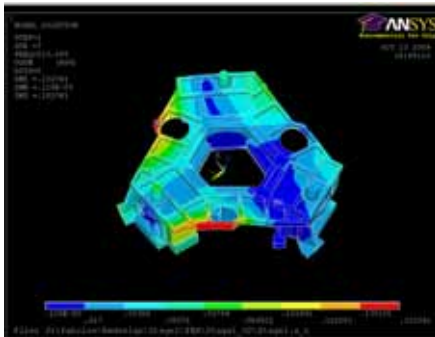Corners are "connected" and a hole is made for the GS13.

Progress:
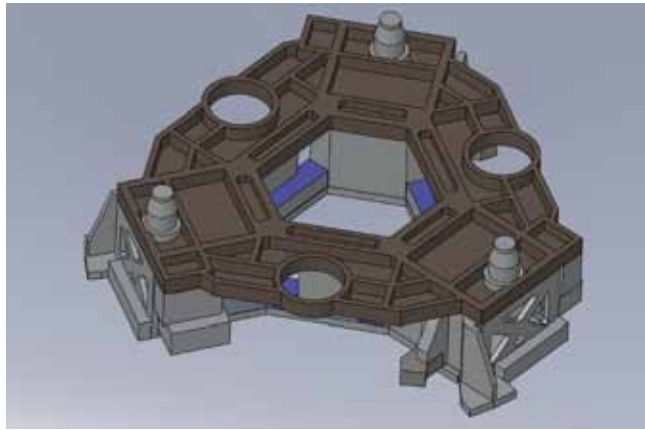-Bending modes are raised from 195Hs to 269Hz.

Regress
- Torsion modes are lowered from 229 to 214Hz.
- A local mode appears at 269Hz
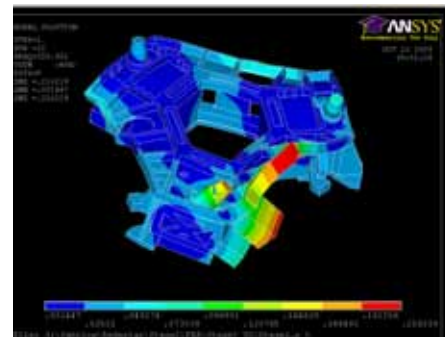
1.3 Version 3

V3, 372 Lbs

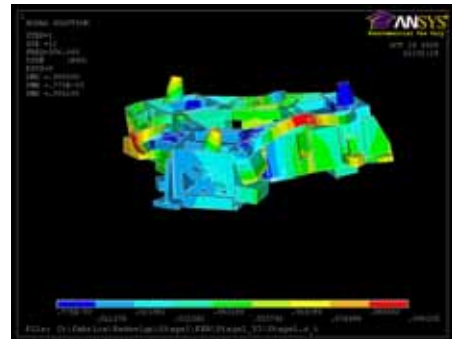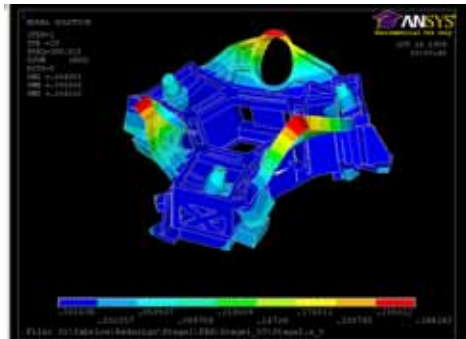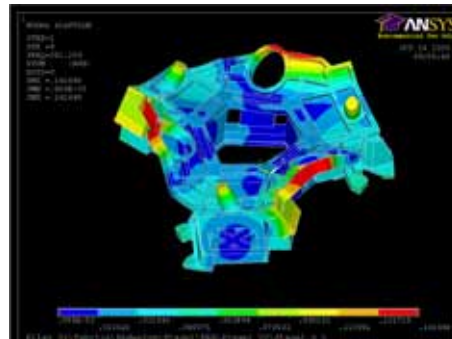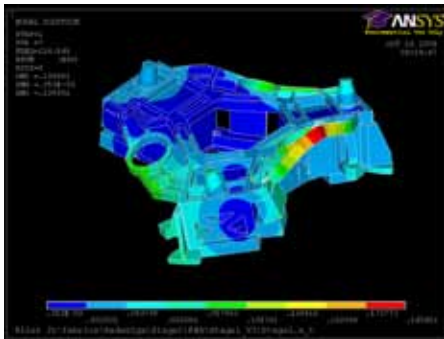|	V1, 237 Lbs	V2, 352 Lbs	V3, 372 Lbs
1	195	214	215
2	195	214	215
3	229	269	282
4	229	298	301
5	287	299	306
6	319	321	306
7	319	322	318
8	335	324	319
9	352	361	363

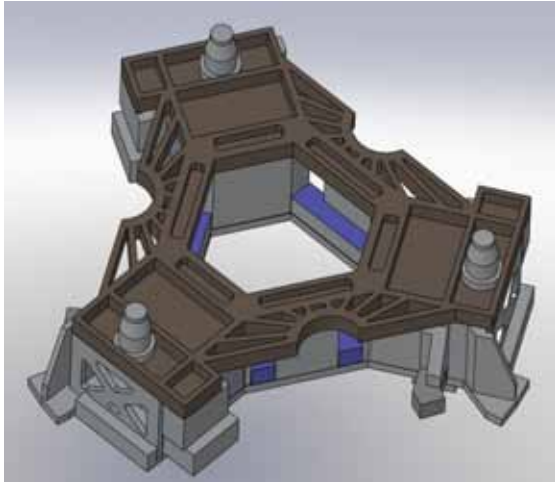Gs13 has been moved outward.

Progress:
-Local bending mode is raised from 262 to 282Hz.

Regress
- Heavier
- A second local bending mode appear
- No improvement on torsion modes

1.4   Version 4

Gs13 has been moved toward center. Close out plate doesn't circle any more the GS13. Trying to suppress the local modes
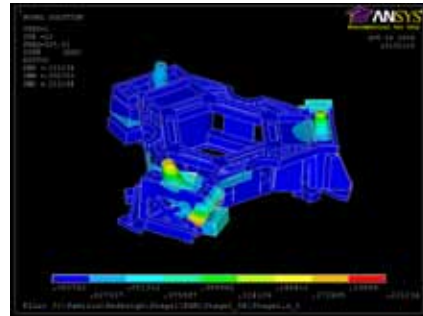
Progress:
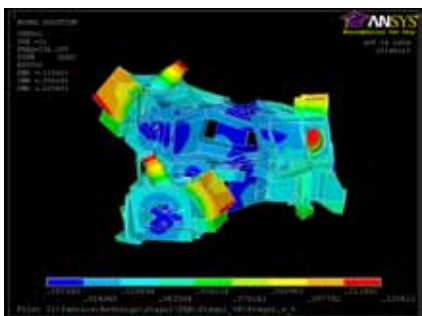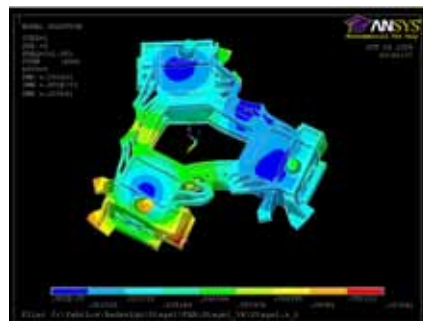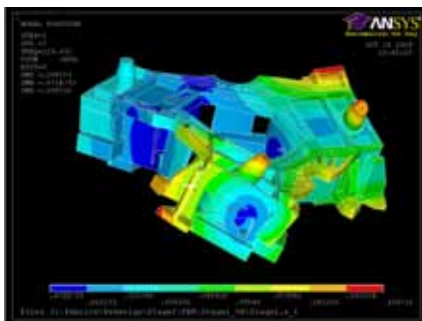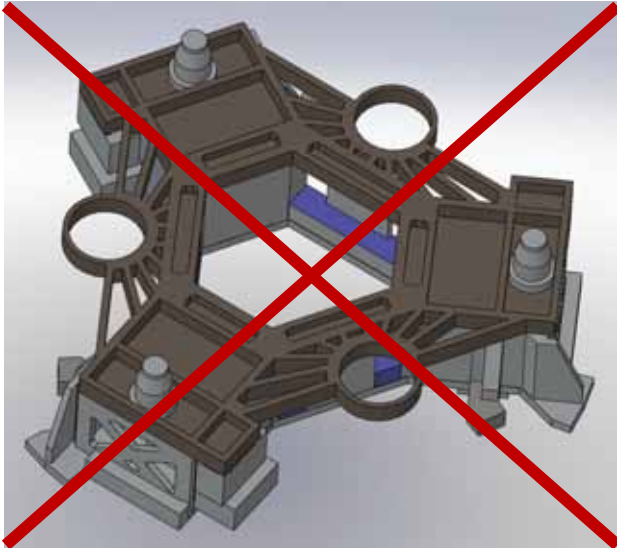- No more degradation of the torsion modes.
- No more local modes

Regress
- Bending modes a bit lower

Conclusion: it's a better compromise.

V4, 323 Lbs

	V1, **237 Lbs**	V2, 353 Lbs	V3, 372 Lbs	V4, 323 Lbs
1	195	214	215	230
2	195	214	215	230
3	229	269	282	262
4	229	298	301	262
5	287	299	306	291
6	319	321	306	325
7	319	322	318	325
8	335	324	319	343
9	352	361	363	366

1.5   Version 5

Picture 2 on previous page shows that the circle is the weak point of the structure. Trying here to reinforce it.
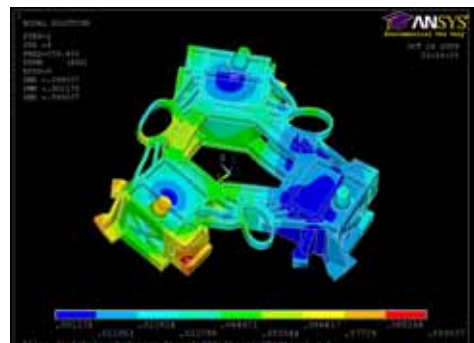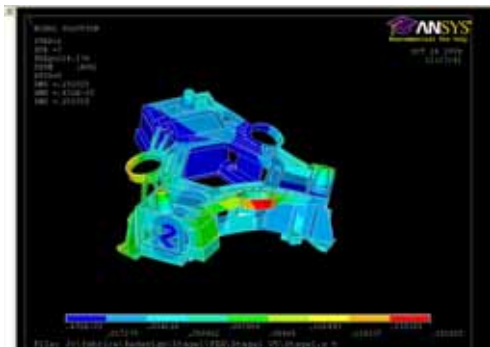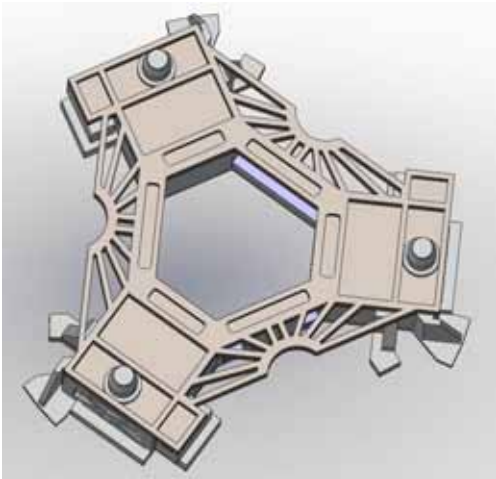
Progress:
- No Progress

Regress
- Most of the modes lower

Conclusion: it's a bad idea. V4 should be used as reference for next analysis.

V5, 341 Lbs

	V1, 237 Lbs	V4, 323 Lbs	V5, 341 Lbs
1	195	230	224
2	195	230	224
3	229	262	259
4	229	262	260
5	287	291	291
6	319	325	325
7	319	325	325
8	335	343	343
9	352	366	363

1.6 Verion 6

V6, 335 lbs

Back to a half circle. The center of the circle is pushed 2" outward

Progress:
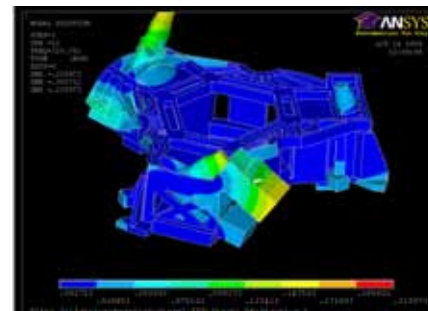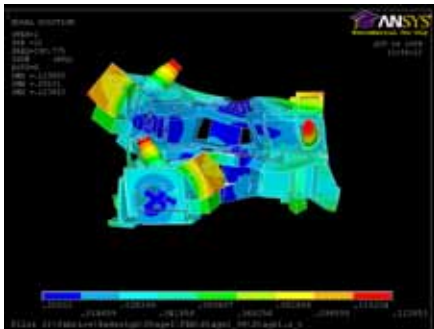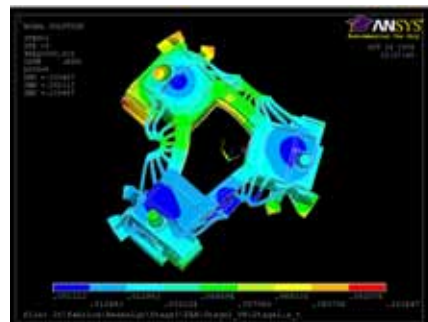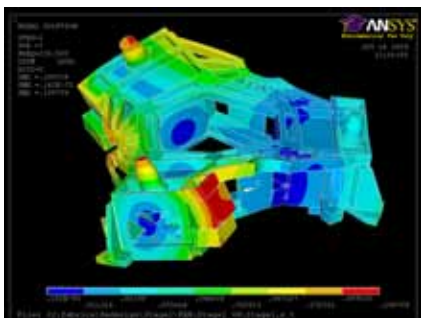- Improve the bending modes from 262Hs to 281Hz.

Regress
- A bit heavier, but the progress worth the extra mass

Conclusion: V6 should be used as reference for next analysis.

	V1, 237 Lbs	V4, 323 Lbs	V6, 335 Lbs
1	195	230	229
2	195	230	229
3	229	262	281
4	229	262	281
5	287	291	291
6	319	325	326
7	319	325	326
8	335	343	344

1.7 Version 7

V7, 320 Lbs

Webbing has been reworked
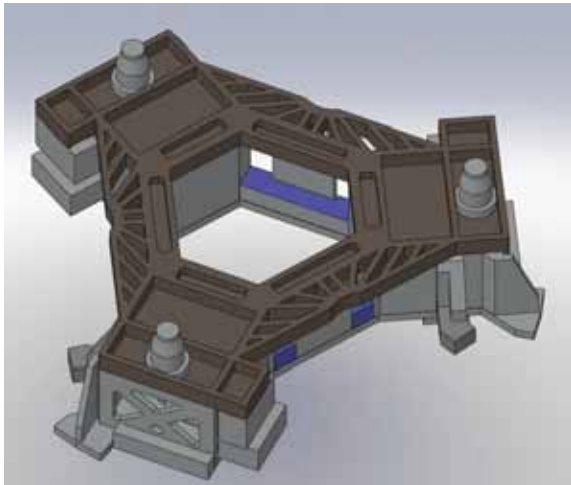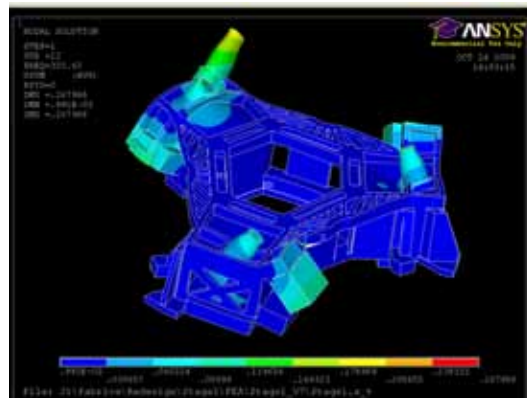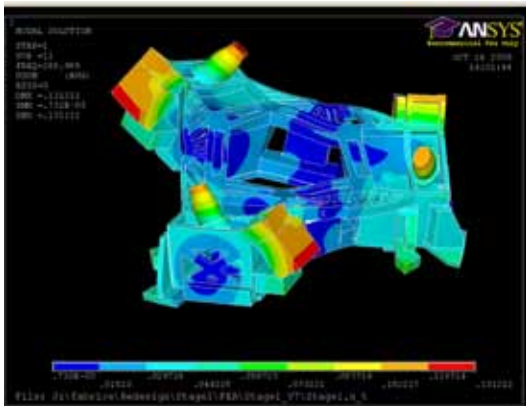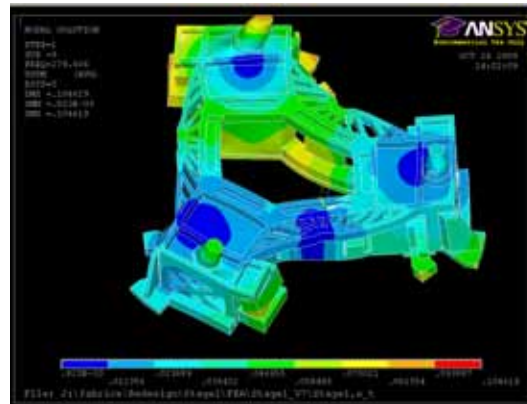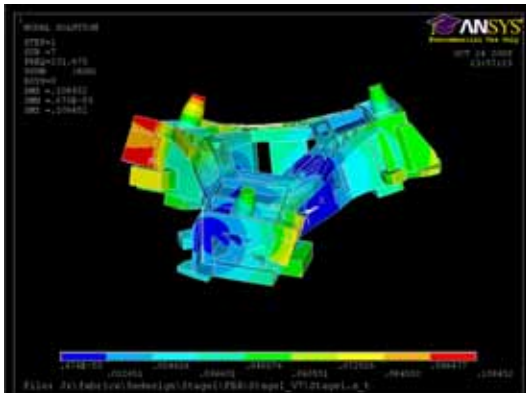
Progress:
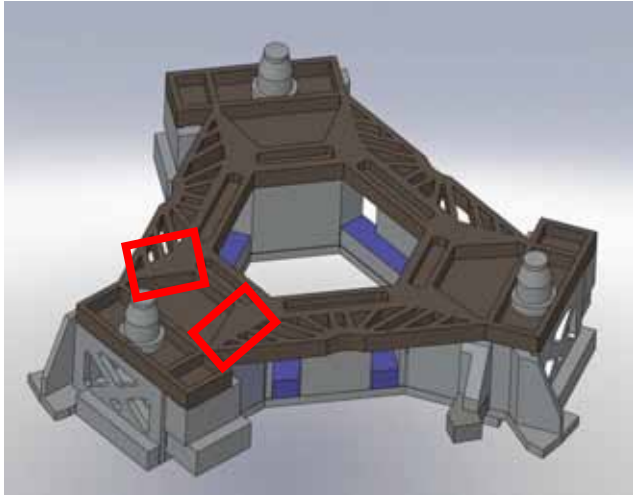- Lighter and as good performances

Regress
- A bit heavier, but the progress worth the extra mass

Conclusion: V7 should be used as reference for next analysis.

	V1, 237 Lbs	V6, 335 Lbs	V7, 320 Lbs
1	195	229	232
2	195	229	232
3	229	281	280
4	229	281	280
5	287	291	289
6	319	326	323

1.8 Version 8

V8, 344 lbs

The material shown in the red boxes has been added to improve the torsion modes

Progress:
- Very few improvement on the torsion modes

Regress
- Heavier

Conclusion: Not worth.

	V1, 237 Lbs	V6, 335 Lbs	V7, 320 Lbs	V8, 344 Lbs
1	195	229	232	234
2	195	229	232	234
3	229	281	280	281
4	229	281	280	281
5	287	291	289	293
6	319	326	323	326
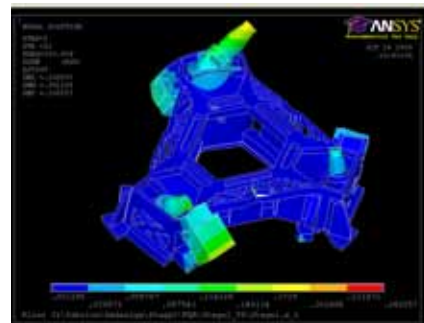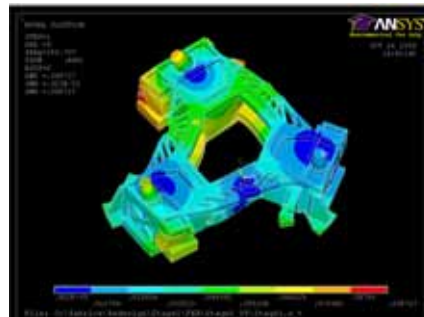
1.9 Version 9
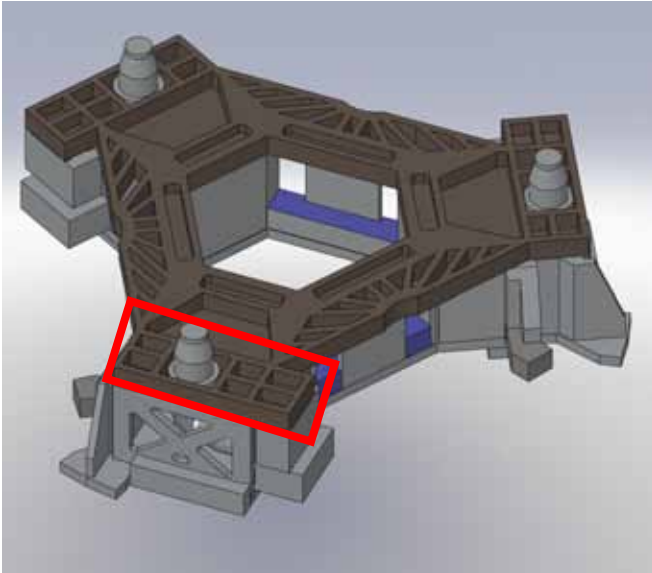
The material shown in the red boxes has been added to improve the local modes of the actuator
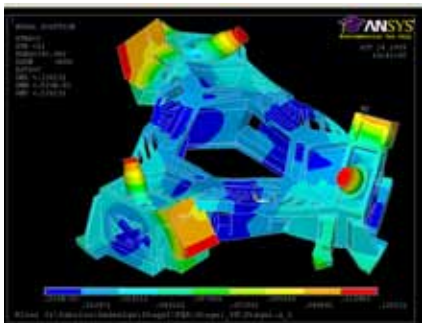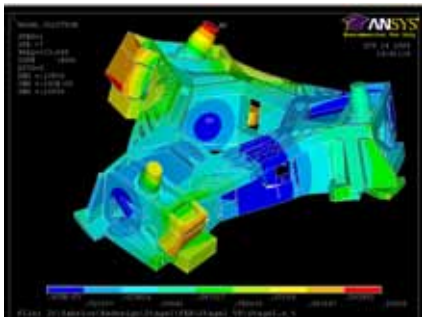
Progress:
- Good progress on the actuator modes.

Conclusion: V9 should be used as reference for next analysis.
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V9, 360lbs

	V1, 237 Lbs	V6, 335 lbs	V7, 320 Lbs	V8, 344 lbs	V9, 360 lbs
1	195	229	232	234	234
2	195	229	232	234	234
3	229	281	280	281	282
4	229	281	280	281	282
5	287	291	289	293	298
6	319	326	323	326	344
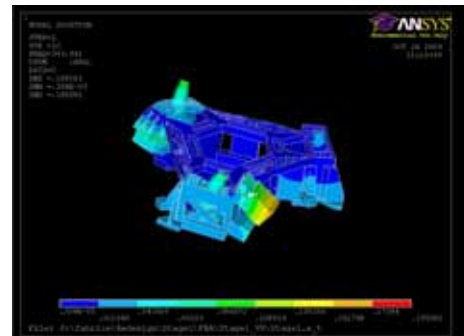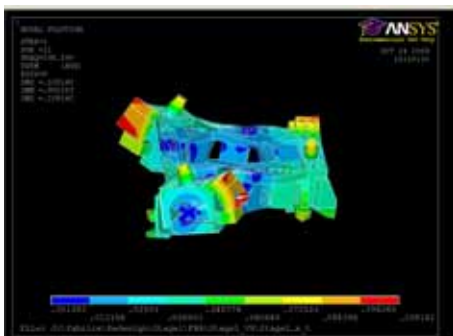
1.10 Version 10

V10, 363lbs

The material shown in the red boxes has been added as an alternative to improve the local modes of the actuator with less material:

Progress:
- Some progress on the actuator modes.

Conclusion: V9 can be kept as reference for next analysis (easier to machine).
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	V1, 237 Lbs	V6, 335 lbs	V7, 320 Lbs	V8, 344 lbs	V9, 360lbs	V10, 363lbs
1	195	229	232	234	234	235
2	195	229	232	234	234	235
3	229	281	280	281	282	279
4	229	281	280	281	282	279
5	287	291	289	293	298	300
6	319	326	323	326	344	349

1.11 Version 11

V11, 367 Lbs

The plate shown in the red boxes has been added as to improve the local modes of the actuator with less material:

This material far from the neutral axis of the bending mode should provide good resistance.

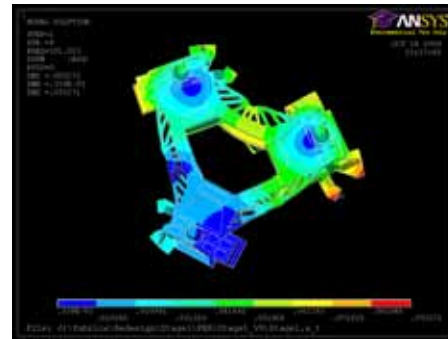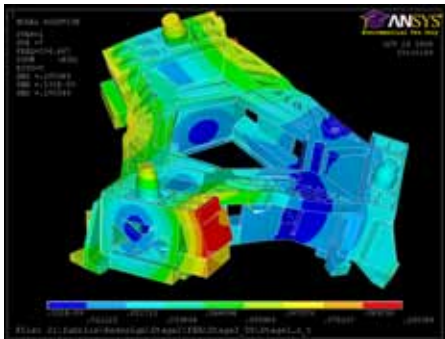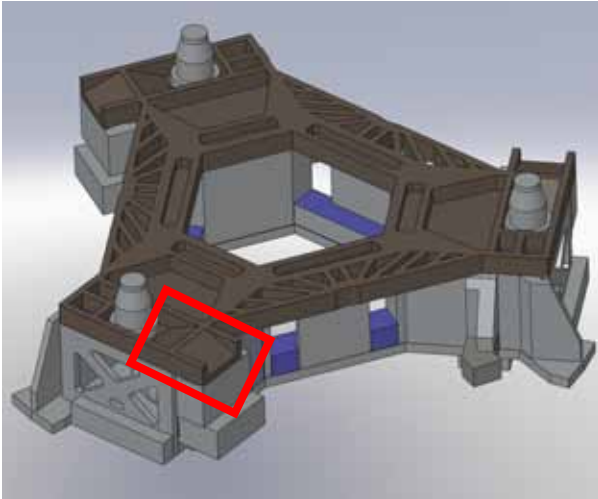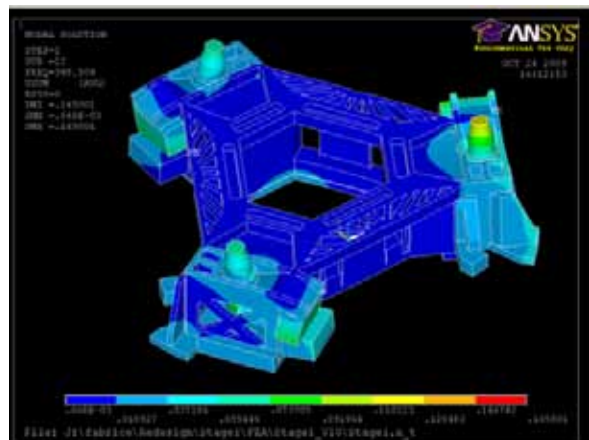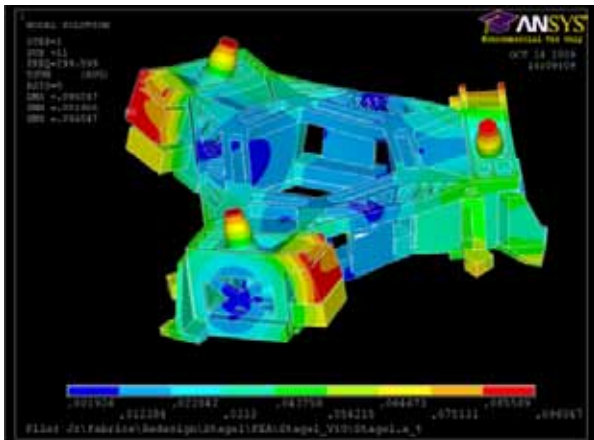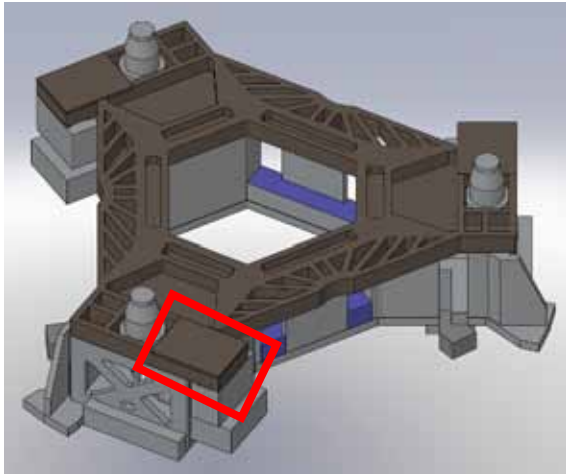Progress:
- Good progress on the actuator modes.

Conclusion: V11 should be used as reference for next analysis.

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	V1, 237 Lbs	V7, 320 Lbs	V9, 360lbs	V11, 367lbs
1	195	232	234	234
2	195	232	234	234
3	229	280	282	282
4	229	280	282	282
5	287	289	298	298
6	319	323	344	352

1.12 Version 12

V12 363 Lbs

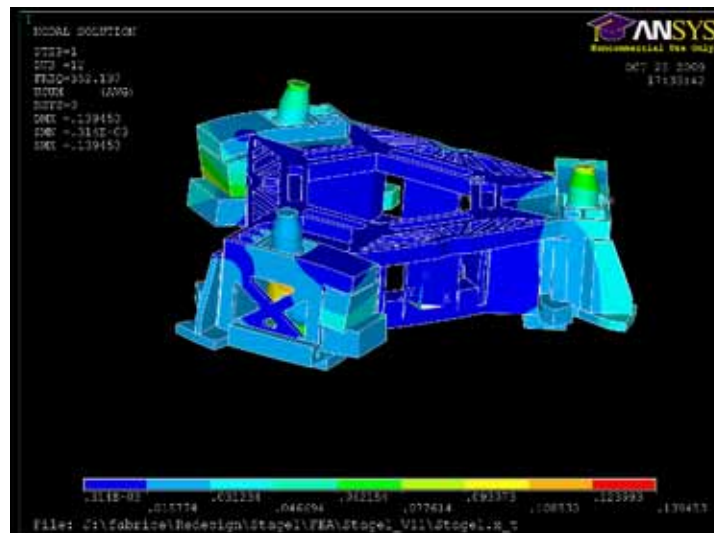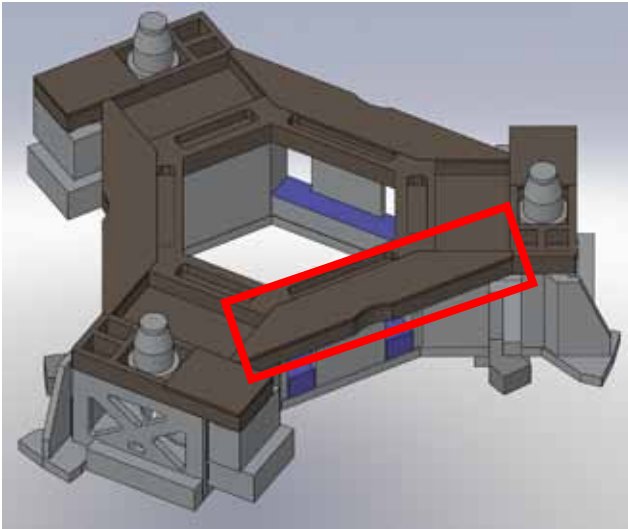The plate shown in the red boxes has been added as to improve the global bending modes.

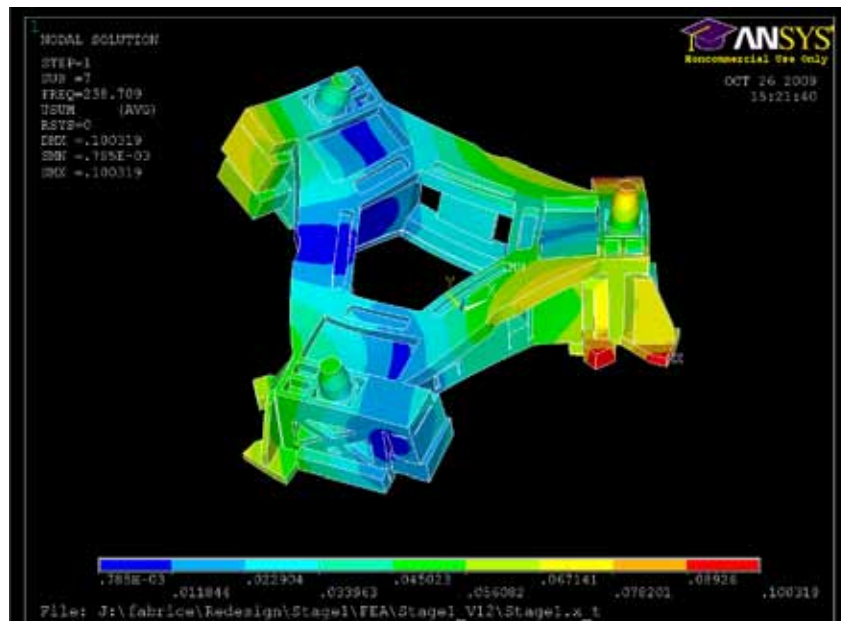This material far from the neutral axis of the bending mode should provide good resistance.
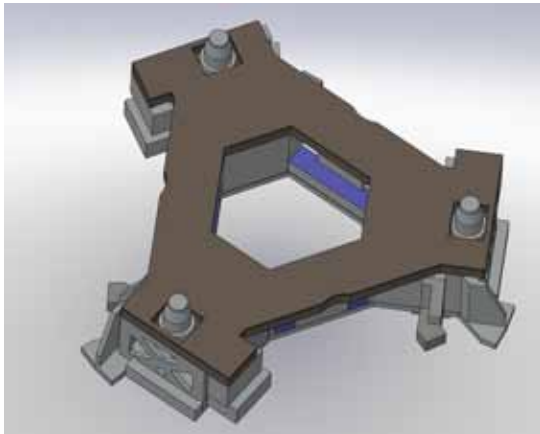
Progress:
- Good progress on most of the modes.

Conclusion: V12 should be used as reference for next analysis.
.

	V1, 237 Lbs	V11, 367 Lbs	V12, 363 Lbs
1	195	234	239
2	195	234	239
3	229	282	302
4	229	282	305
5	287	298	305
6	319	352	359

1.13 Version 13

V13,   399 Lbs

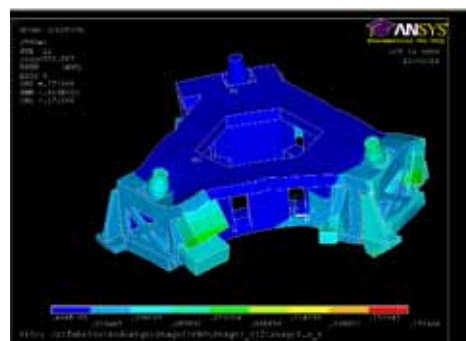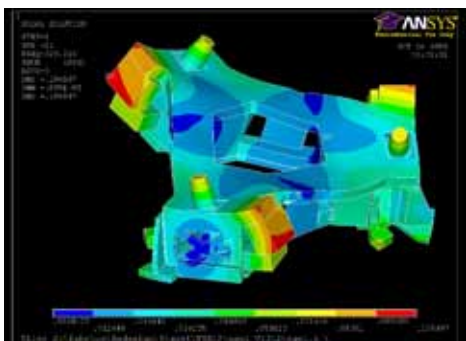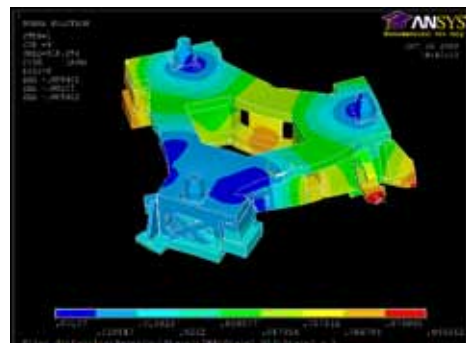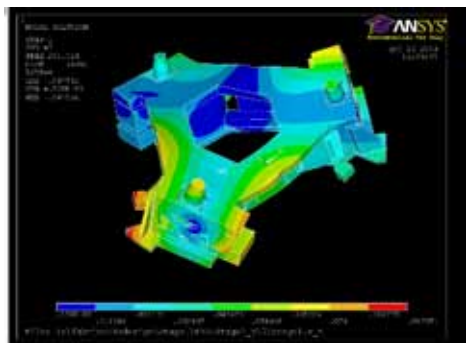|	V1, 237 Lbs	V12, 363 Lbs	V13, 399 Lbs
1	195	239	254
2	195	239	254
3	229	302	318
4	229	305	318
5	287	305	329
6	319	359	371

Since the plates added in the last two versions have provided good stiffness their used is generalized: a cover is used on the whole surface.

The right picture shows the webbing inside the box

Progress:
- Very good progress on all of the modes.

Conclusion: V13 should be used as reference for next analysis.

1.14 Version 14
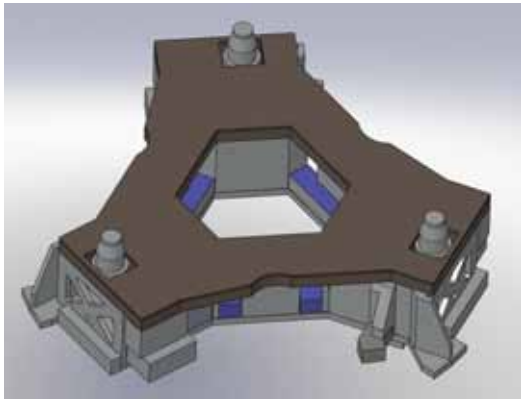
V14, 420 Lbs
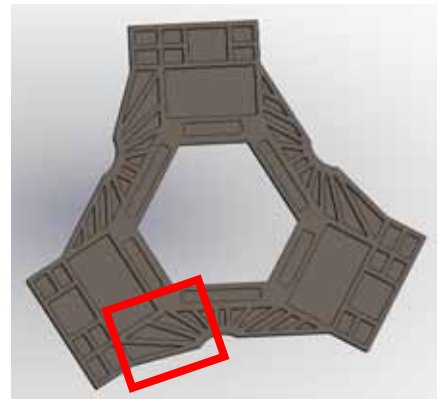
	V1, 237 Lbs	V12, 363 Lbs	V13, 399 Lbs	V14, 420 Lbs
1	195	239	254	254
2	195	239	254	254
3	229	302	318	334
4	229	305	318	337
5	287	305	329	337
6	319	359	371	372

The webbing in the red box has been modified.

It provides good progress on bending and actuator and bending modes but no progress on the lowest torsion modes which is the priority.

Conclusion: V13 will be kept as reference for next analysis.
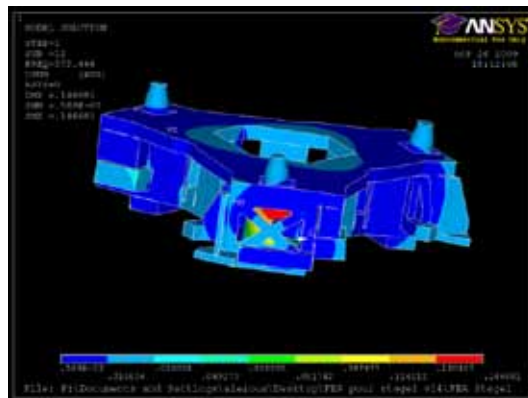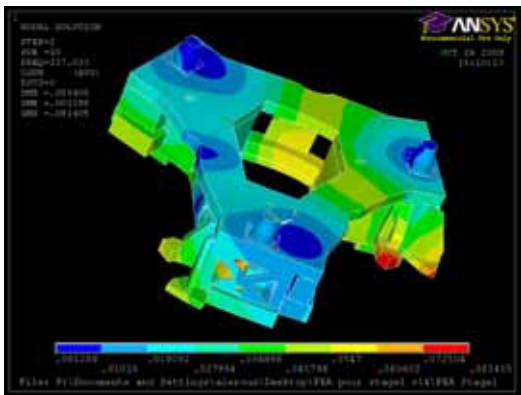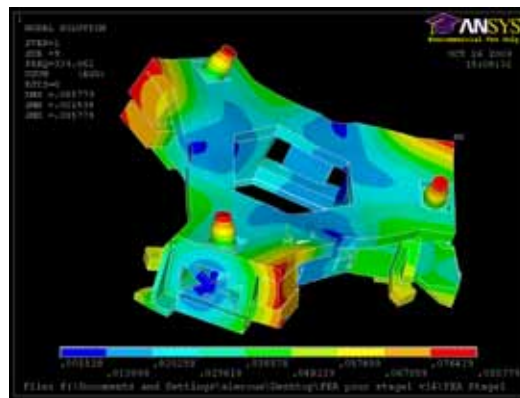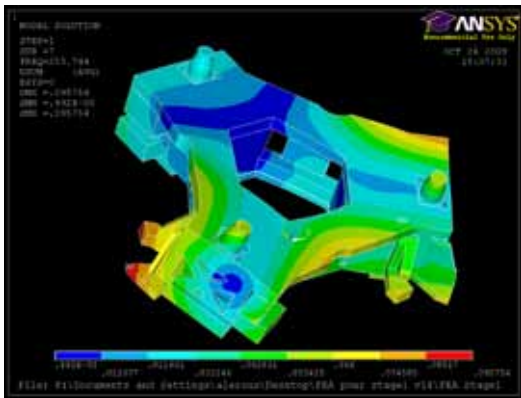
1.15 Version 15
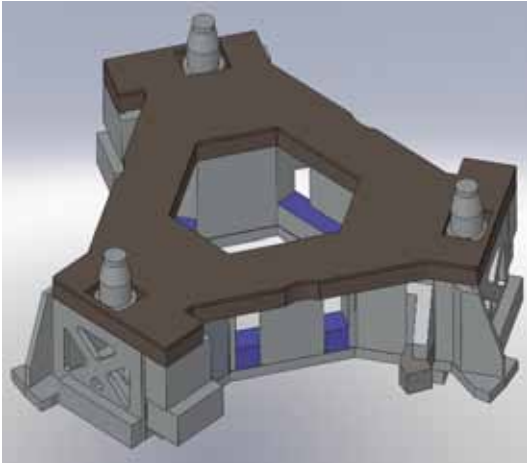
V15, 395 Lbs

	V1, 237 Lbs	V13, 399 Lbs	V15, 395 Lbs
1	195	254	254
2	195	254	254
3	229	318	319
4	229	318	319
5	287	329	329
6	319	371	371

The webbing in the red box has been modified.

A finer webbing has been used.

Conclusion: I provides results as good as V13. V15 will be used as reference for next analysis.

1.16 Version 16
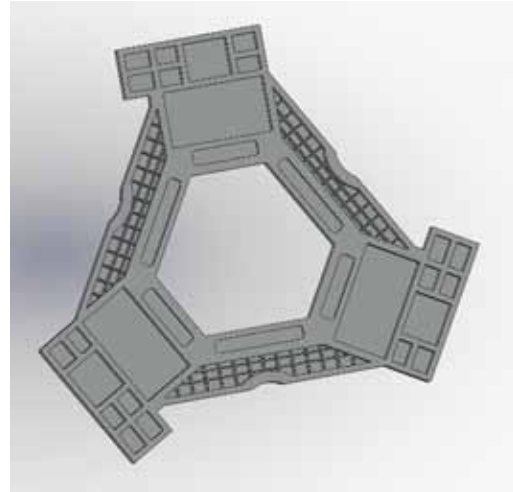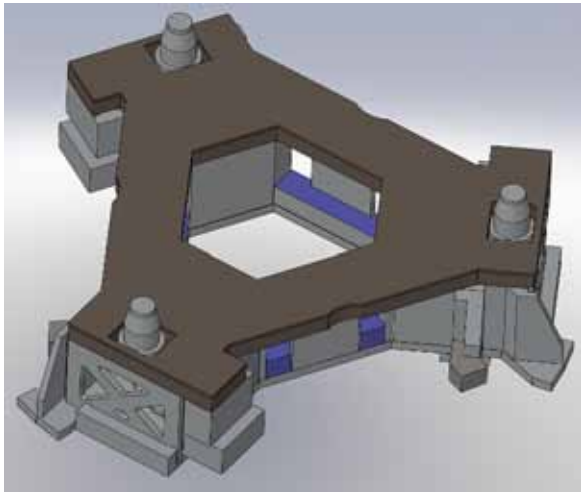
V16, 385 Lbs

	V1, 237 Lbs	V15, 395 Lbs	V16, 385 Lbs
1	195	254	255
2	195	254	255
3	229	319	314
4	229	319	314
5	287	329	328
6	319	371	370

The webbing has been modified to alight the structure.

Conclusion: I provides results as good as V15. V16 will be used as reference for next analysis.
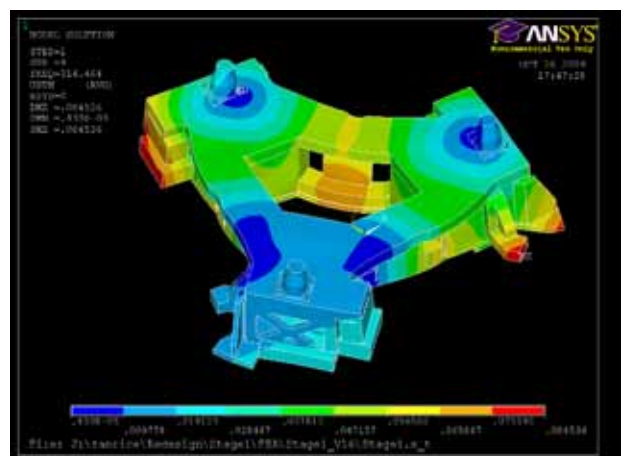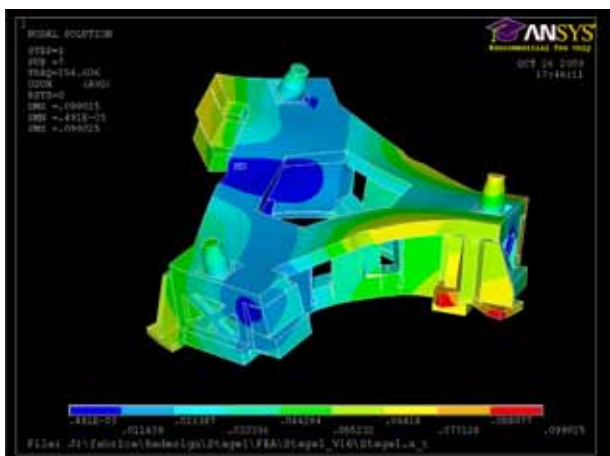
1.17 Version 17
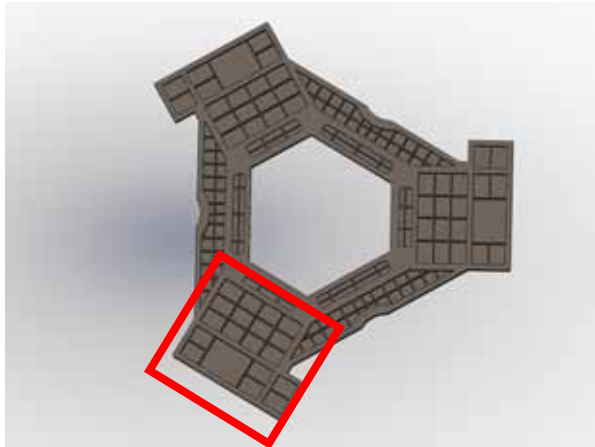
V17, 379 Lbs

	V1, 237 Lbs	V16, 385 Lbs	V17, 379 Lbs
1	195	255	255
2	195	255	255
3	229	314	314
4	229	314	314
5	287	328	328
6	319	370	368

The webbing has been modified to alight the structure.

Conclusion: I provides results as good as V16. V17 will be used as reference for next analysis.
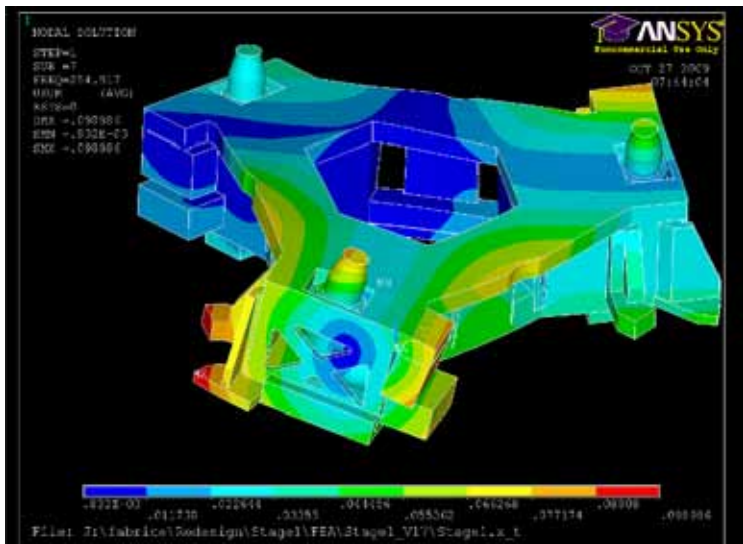
1.18 Version 18
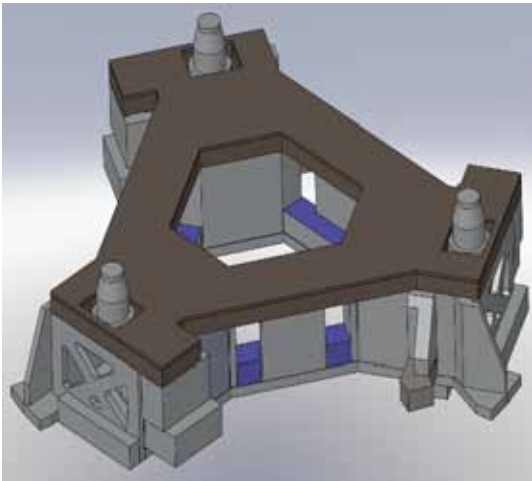
376 Lbs

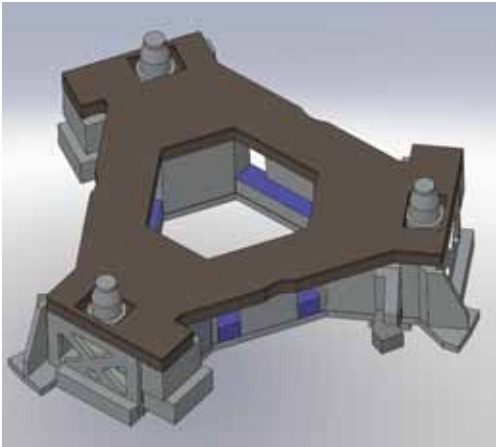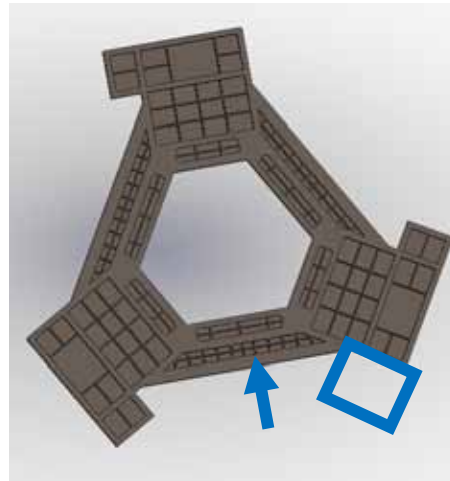|	V1, 237 Lbs	V17, 379 Lbs	V18, 376 Lbs
1	195	255	254
2	195	255	254
3	229	314	302
4	229	314	302
5	287	328	326
6	319	368	364

The stiffening component has been pushed toward the center to accommodate for the loading tool of the blades. The arrow illustrates how the material has been pushed toward the center. The blue box illustrates the space that must remains free for the loading tool

A larger thickness has been used to maintain a similar stiffness.

Conclusion: We lose performance on the bending mode, but it's necessary for the assembly of the loading tool.
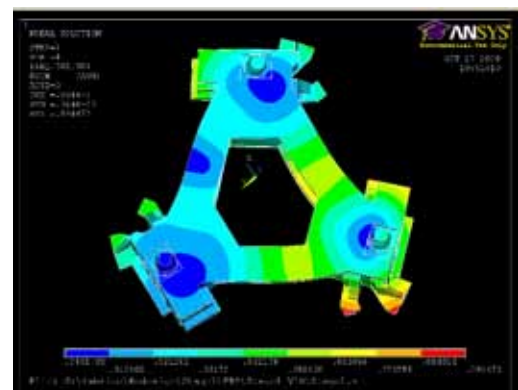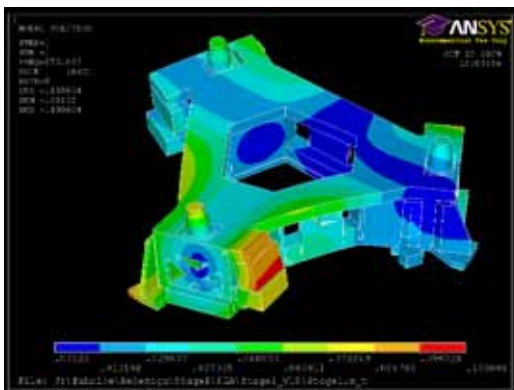
1.19 Version 19
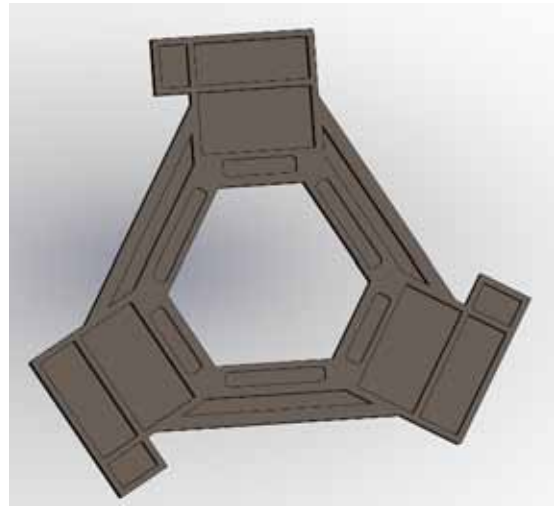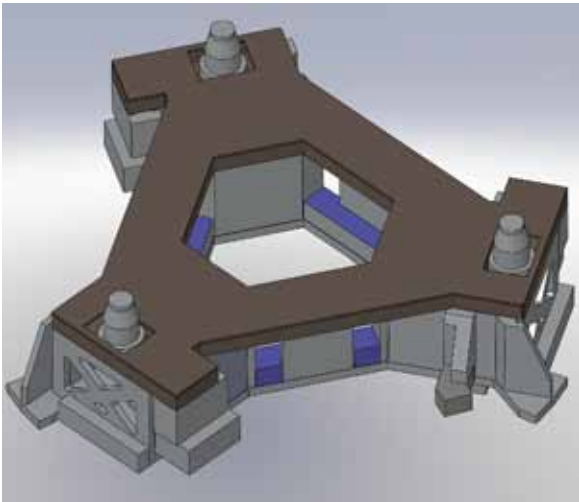
V19, 341 Lbs

On this version, the webbing as been removed to evaluate its actual influence on the overall stiffness.

Conclusion: webbing is very useful.
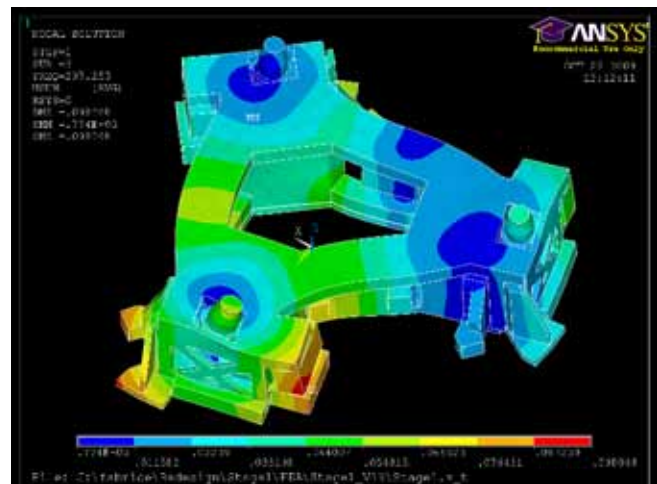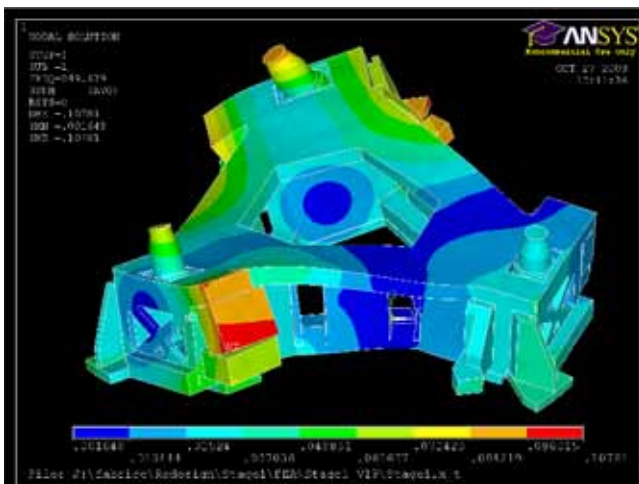
1.20 Final Close out plate design

Close out plate & Loading tool
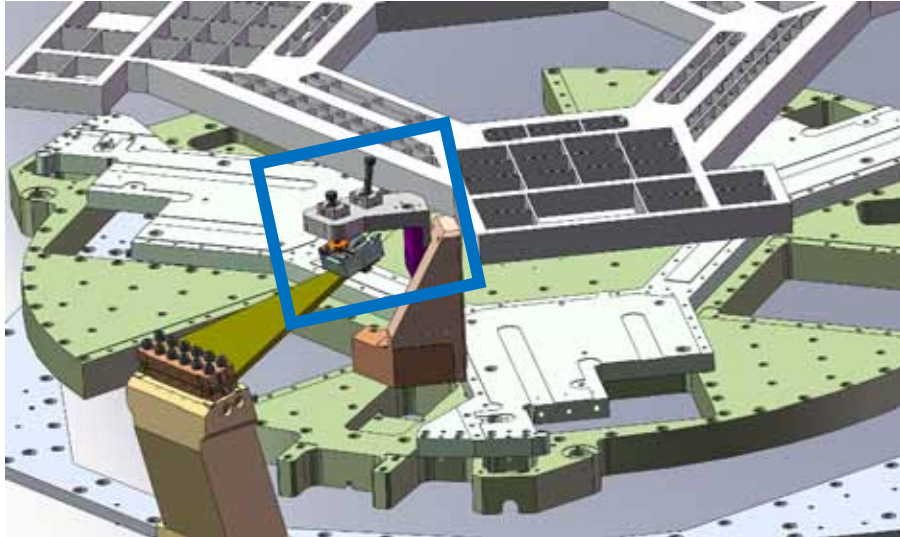
One bracket modification:
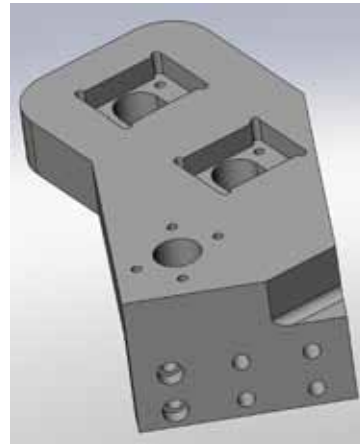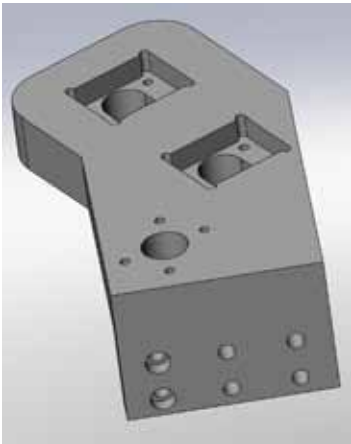
2   Influence of Lateral stiffeners

Version 20
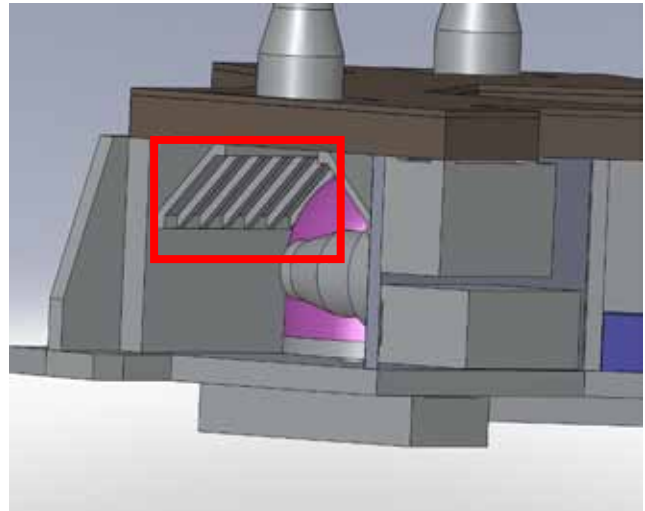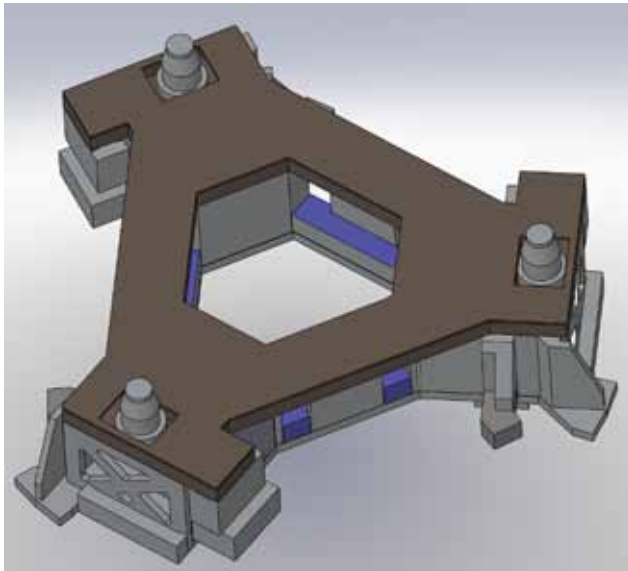
	V1, 237 Lbs	V19, 341 Lbs	V20, +54 Lbs
1	195	250	255
2	195	250	255
3	229	297	301
4	229	297	301
5	287	313	325
6	319	349	365

Ribs have been added.

Conclusion: some improvements on global modes. It will be probably even more useful on the local modes.
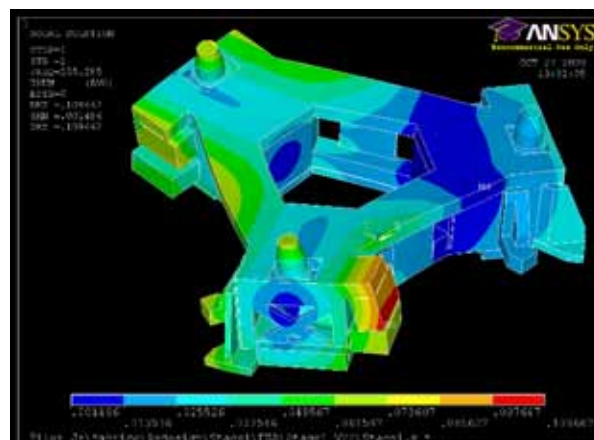
3   Influence of the ballast mass
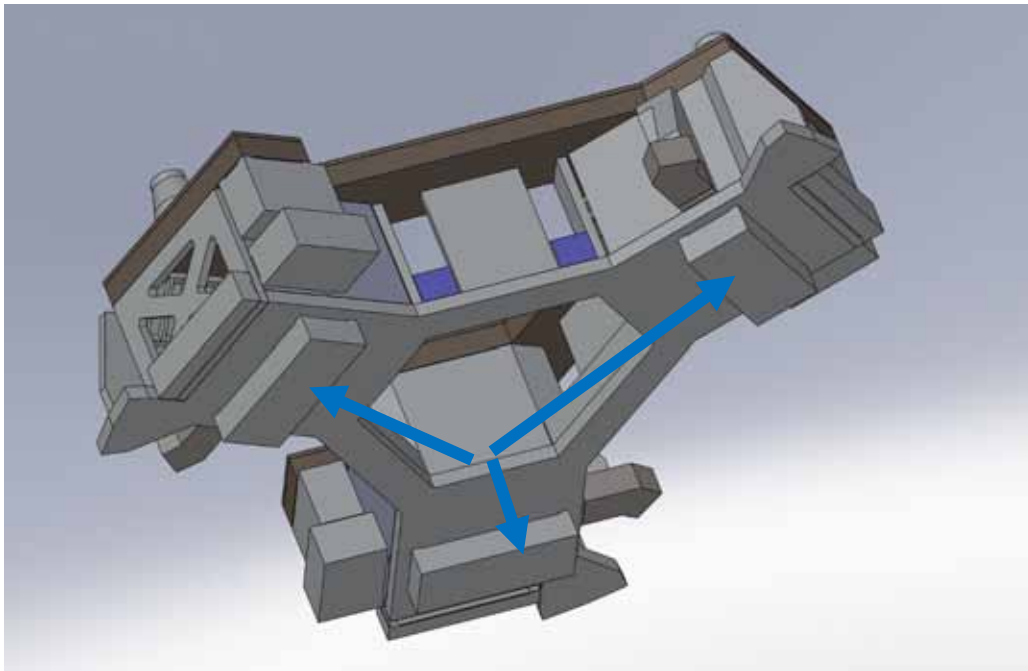
	V21 (Balllast = 31 Lbs)	V22 (Balllast = 61 Lbs)	V23 (Balllast = 94 Lbs)
1	255	247	242
2	255	247	242
3	301	298	296
4	301	298	296
5	325	319	314
6	366	364	365

4 Mass Budget & Center of mass position

1. Initial Design

Mass budget:				Ref is the bottom of the baseplate			
	Mass	Count	Total Mass	CG Position, in	Mass*CG (m.in)		
Structure - (Close out Plate) - (Ballast)	642.5	1.0	642.5	4.77	3064.7		
Close out Plate	231.5	1.0	231.5	14.97	3466.5		
Ballast	75.6	3.0	226.8	-1.85	-419.6		
Vertical Actuators	33.0	3.0	99.0	10.79	1068.2		
Horizontal Actuators	33.0	3.0	99.0	2.50	247.5		
Vertical L4C	18.8	3.0	56.4	16.82	948.6		
Horizontal L4C	18.8	3.0	56.4	2.50	141.0		
STS2	117	3.0	351.0	4.54	1593.5		
Stage1 Total			1762.6	5.74	10111	CG Offset :	3.24
Check with Solidworks							
Stage1 Total			1778	5.77		CG Offset :	3.27

2. Protoype at LASTI

	Mass	Count	Total Mass	CG Position	Mass*CG		
Stage1 Total	1778	1.0	1778	5.77	10259.1		
Top Trim masses	380	1.0	380.0	16.00	6080.0		
Bottom Trim masses	60	1.0	60.0	2.00	120.0		
Stage1 Total			2218.0	7.42	16459	CG Offset :	4.92

3. AdL Design

| Mass budget:				Ref is the bottom of baseplate			
	Mass	Count	Total Mass	CG Position, in	Mass*CG (m.in)		
Structure - (Close out Plate) - (Ballast)	681	1	681	4.56	3105.36		
Close out Plate	380	1	380	15.05	5719		
Stiffeners	18	3	54	11.4	615.6		
Ballast	31	3	93	-1.5	-139.5		
Vertical Actuators	25	3	75	11.5	862.5		
Horizontal Actuators	25	3	75	2.5	187.5		
Vertical L4C	18.8	3	56.4	16.3	919.32		
Horizontal L4C	18.8	3	56.4	5	282		
Trillium	73	3	219	4.97	1088.43		
Trim mass	30	3	90	1	90		
Stage1 Total			1780	7.15	12730	CG Offset :	4.65

As a function of Ballast Mass:

	V21 (Balllast = 31 Lbs) CG Offset = 4.65	V22 (Balllast = 61 Lbs) Offset = 4.24	V23 (Balllast = 94 Lbs) Offset = 3.82
1	255	247	242
2	255	247	242
3	301	298	296
4	301	298	296
5	325	319	314
6	366	364	365

5 Conclusion

The close out plate has been studied and analyzed to optimize the stiffness of Stage1.

Successive design and analysis have been done to optimize the stiffness stage 1 and more especially the stiffness over mass ratio of the close out plate. 18 iterations have lead to the concept presented on the two pictures below.
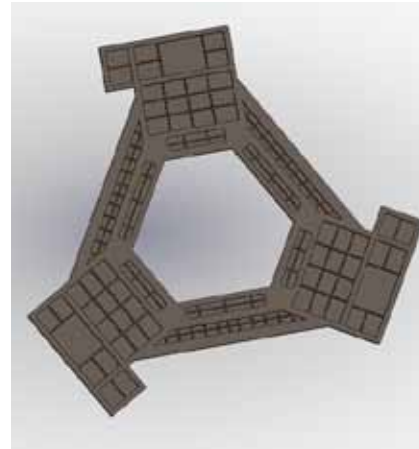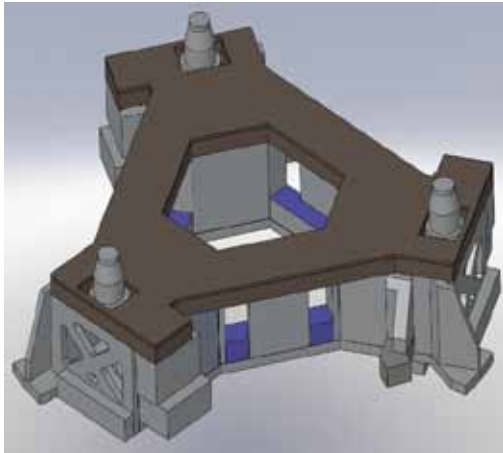
The table below shows the Stage 1 natural frequencies with the initial design (V1) and the final design (V18). Those values overestimate the real stiffness due to the bounded model of the contacts taken into account in the model. However they allow to evaluate the relative improvement.

The first two modes at 195Hz were in plane bending modes. They have moved to 302Hz.

The next modes at 229Hz were torsion modes. They have moved to 254Hz.

The next modes at 287Hz and 319Hz were local modes induced by the vertical actuator. They have moved to 326Hx and 364Hz respectively.

	V1, 237 Lbs	V18, 376 Lbs
1	195 Hz	254 Hz
2	195 Hz	254 Hz
3	229 Hz	302 Hz
4	229 Hz	302 Hz
5	287 Hz	326 Hz
6	319 Hz	364 Hz

The final design of close plate and its new plate cover are presented on the pictures below.
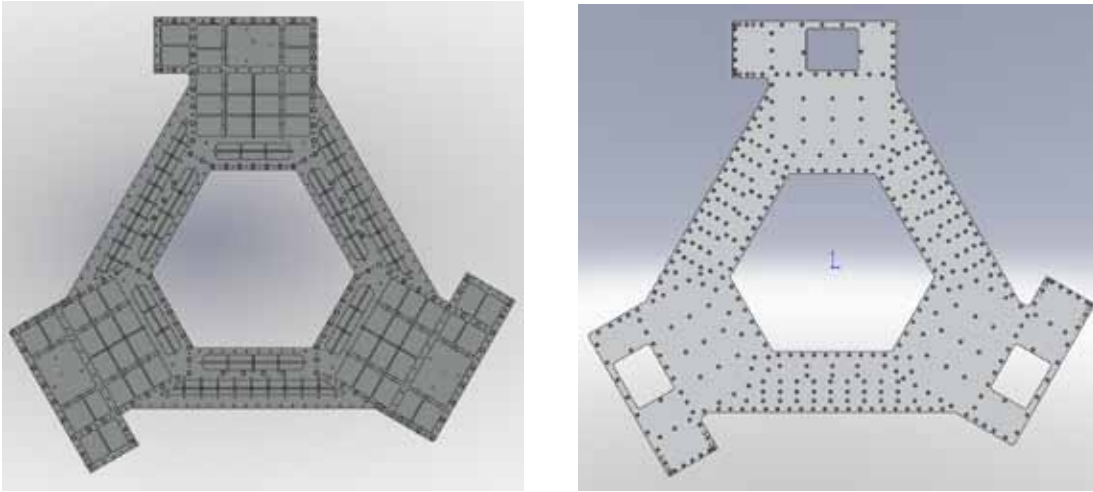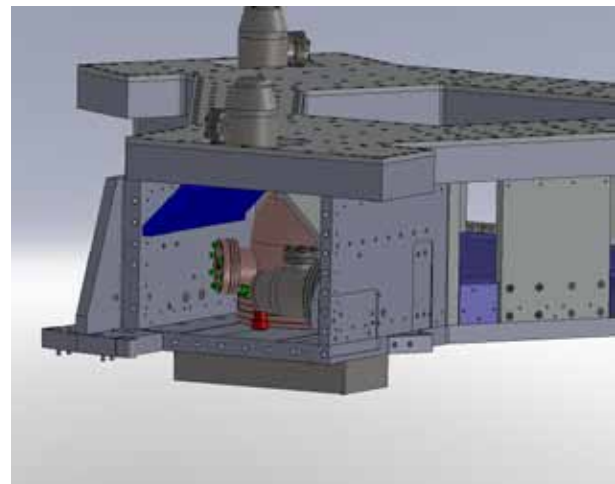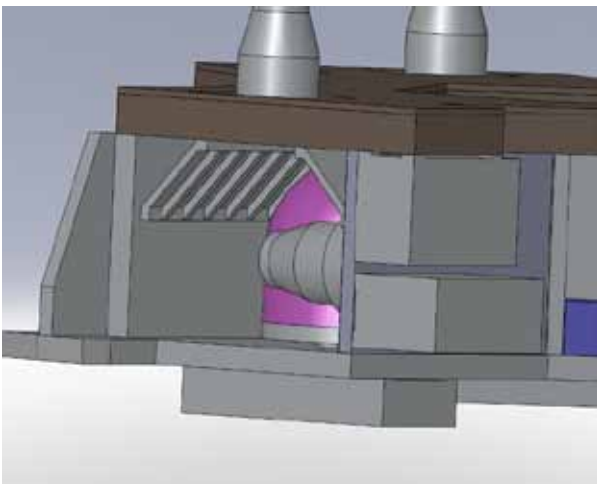

The picture below shows that the new close out plate allows to keep the initial loading tool concept:
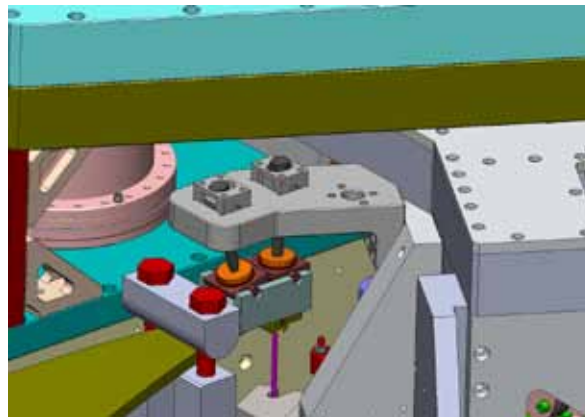
- · **Reinforcement Brackets**

The use of stiffeners has been studied. They provide a good reinforcement for the local modes in the actuators and L4C areas. The left picture shows the concept used for FEA. The right picture shows the actual implementation.

· **L4C Position**

The L4C have repositioned closer to the nodal lines and nodal points has illustrated on the picture below. This should reduce the sensitivity to those modes and improve the transfer functions.
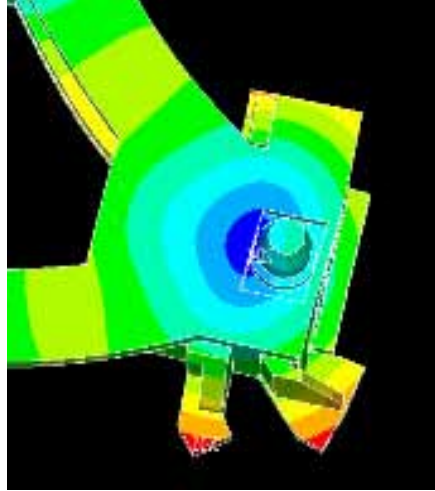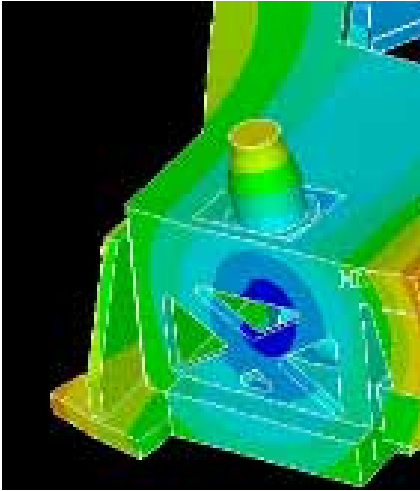
· **Ballast mass**

The influence of the ballast mass on the CG position and the structure modes has been studied.

After discussion within the SEI team it has been decided that 31 Lbs Aluminum ballasts will be used for AdL (vs 75 Lbs Stainless Steel ballasts for the prototype).

This will allow to reduce the effect of these lumped masses on the structure response. Moreover, even with lighter ballast masses the CG position of the final design will be close to the actuator plan than it is on the prototype (the prototype has 400 Lbs of trim mass on the close out plate, plus trim mass on the front doors that won't be necessary for Advanced LIGO thanks to shim adjustment).