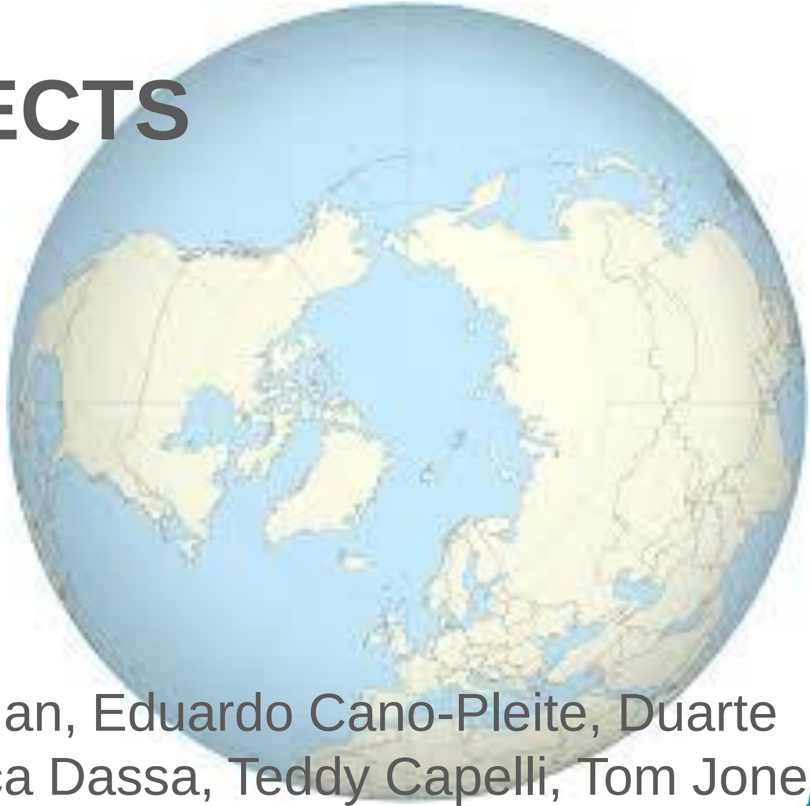
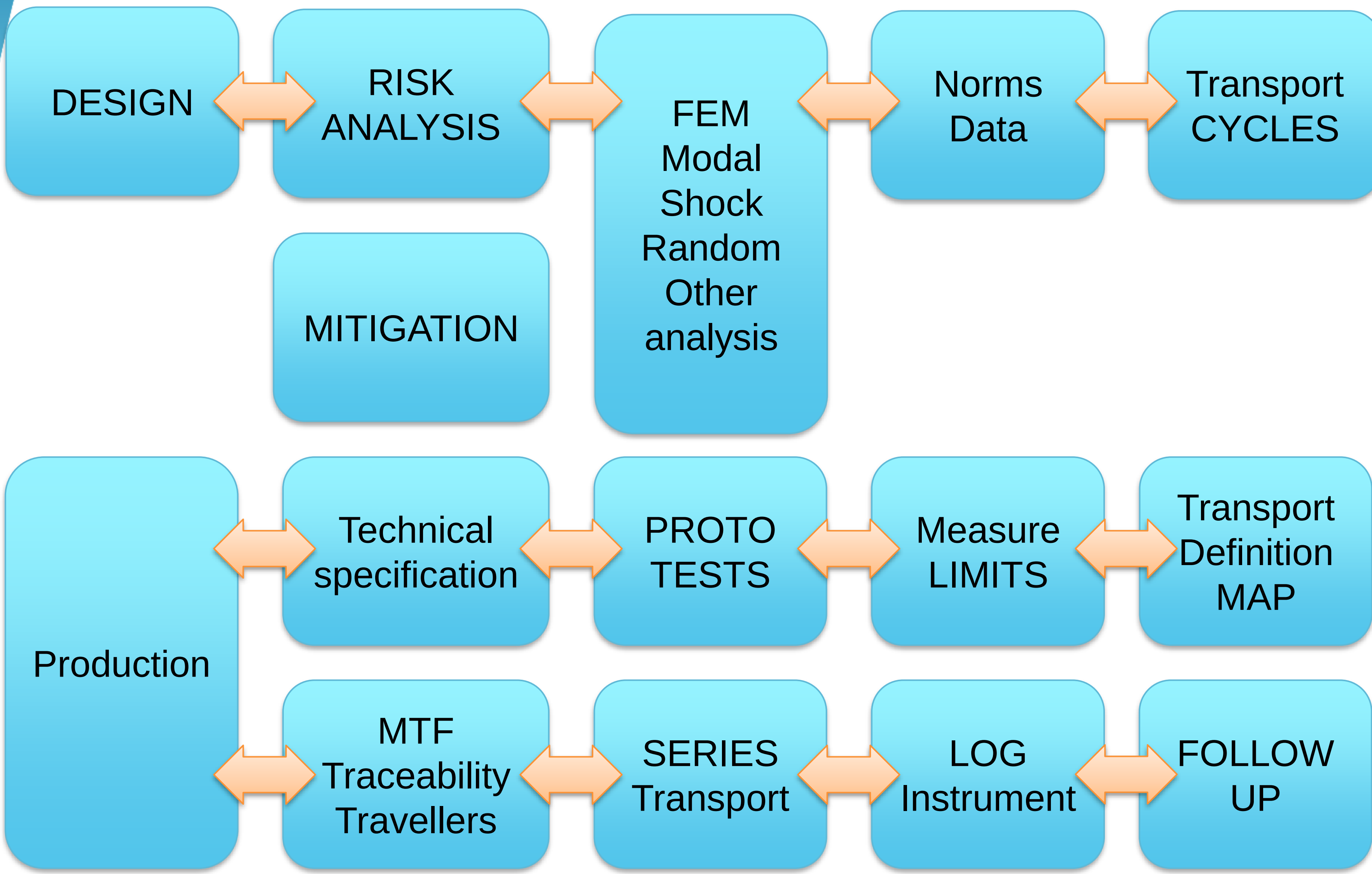
Transport ASPECTS

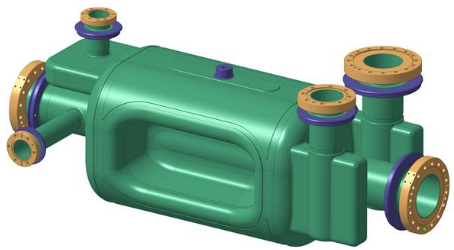
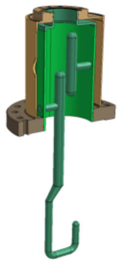
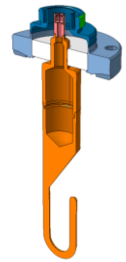
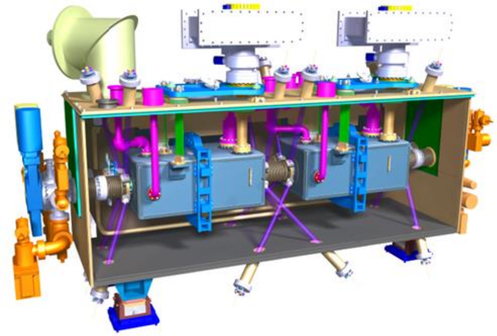


Kurt Artoos, Edward Jordan, Eduardo Cano-Pleite, Duarte Cartaxo Dos Santos, Luca Dassa, Teddy Capelli, Tom Jones

OUTLINE

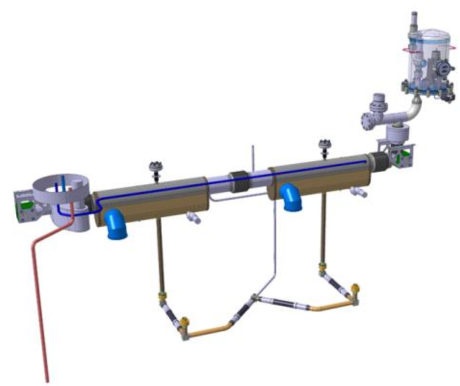

DESIGN
RISK ANALYSIS
FEM Modal Shock Random Other analysis
Norms Data
Transport CYCLES
MITIGATION
Production
Technical specification
PROTO TESTS
Measure LIMITS
Transport Definition MAP
MTF Traceability Travellers
SERIES Transport
LOG Instrument
FOLLOW UP

Risk analysis

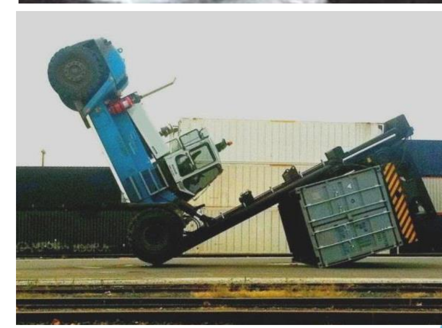
Impact/contact
Untightening screws
Contamination/humidity
Leak
Shock
Vibration
Inclination/support
Fatigue
Temperature
Misalignment
Magnetic/electrical
Air pressure (na)

Loss of equipment during transport
Loss of traceability

Sensitive,
long lead items






Risk analysis

Level of probability (P)	Meaning	Description
1	Very unlikely	Under similar conditions this was rarely or never observed. Several parallel causes are required for this to happen. The process for this to happen is complex
2	Possible	Under similar conditions this has been observed. Some parallel causes are required for this to happen. The process for this to happen is less complex.
3	Certain	Under similar conditions this is a known event. Two parallel causes are required for this to happen. The process for this to happen is easy to imagine.
4	Very likely	Under similar conditions this happened often. A single cause is required for this to happen. The process is evident.

Level of frequency (F)	Number of separate transport actions	Measure the risk by numbers

Level of Gravity (G)	Meaning	Description
1	Minor	Minor consequences, Can be easily rectified. No impact on planning (days). No impact on performance
2	Average	Average consequences. Requires more than one rectification steps. Existing impact on planning (weeks) and/or cost. No clear impact on performance
3	Critical	Significant consequences. Requires several rectification steps with some level of incertitude. Important impact on planning (months) and/or cost. Probable impact on performance
4	Catastrophic	Possible loss of component, high uncertainty on outcome. Major consequence on planning and cost. Performance lost.

Level of detection (D)	Meaning	Description
1	Clearly observable	Will be detected, easily measured
2	Observable	Can be measured with some effort, requires time for observation, measurement with consequence on planning/cost
3	Difficult	Difficult to observe, measurements difficult to interprete, with level of uncertainty, measurements with significant consequences on planning/cost.
4	Not observed	Will only be detected during operation or very late stage with very high consequences on planning/cost.

Risk analysis
«Living document»

Some examples not related to shocks or vibrations:

Contact: Tuner motor directly supported on cavity,
mitigation: blockage or cover

Contamination: bellows and clean room preparation
«Inverted bellows» of tuner and FPC, small parts may fall in

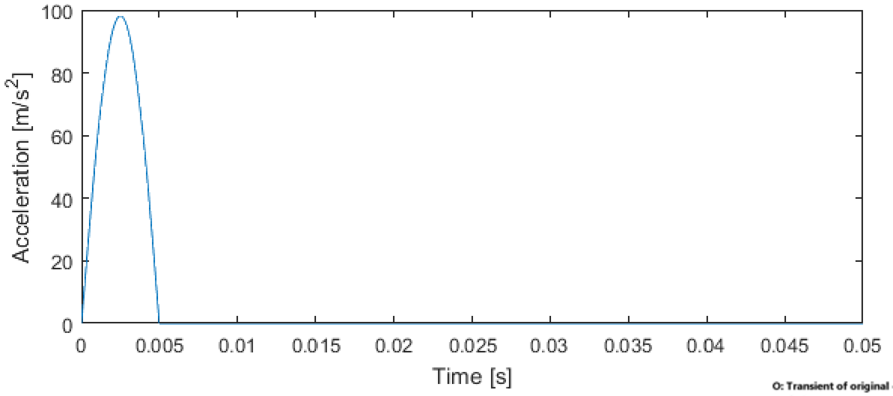
Contact/impact Loss of fiducials
mitigation: protection cover, redundancy ?

Untightening screws: use locking devices, technical specification of tightening torque
Block shear motion, model contacts
Look for contacts with limited number of screws
Certification or Junker tests

Qualitative analysis for design

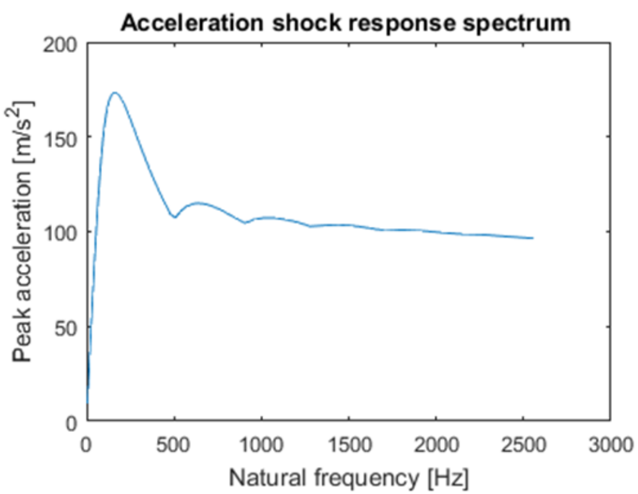
Analysis shocks and random vibration

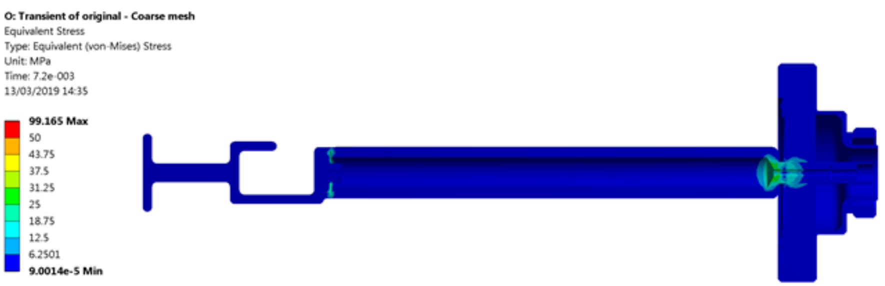
Shock 10g, 20 ms, 1% damping



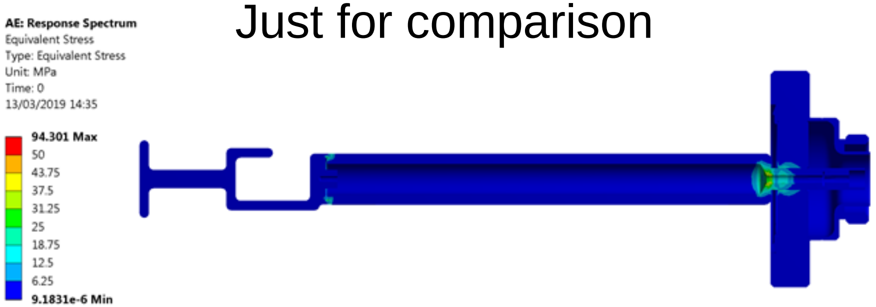
Input acceleration

- Shock response spectrum





Just for comparison



- Transient analysis: time consuming

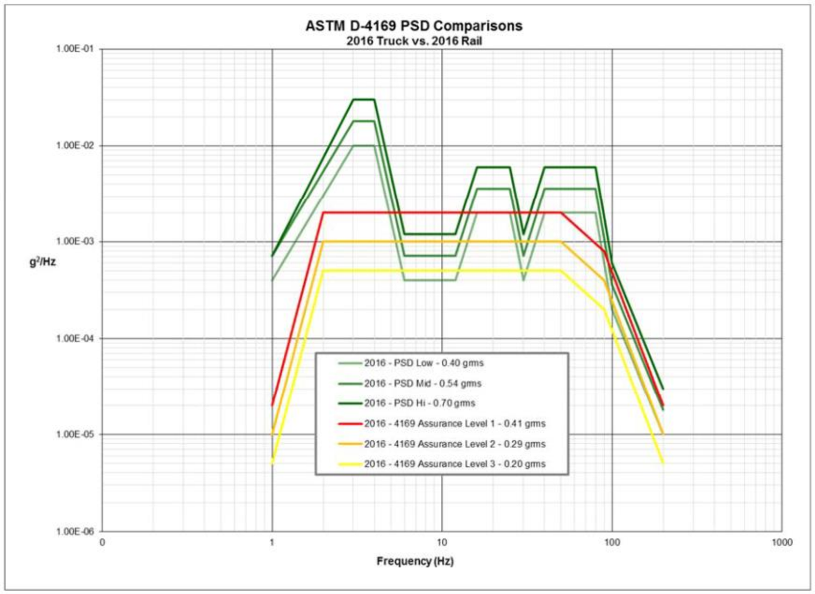
Eduardo Cano-Pleite

Random vibration

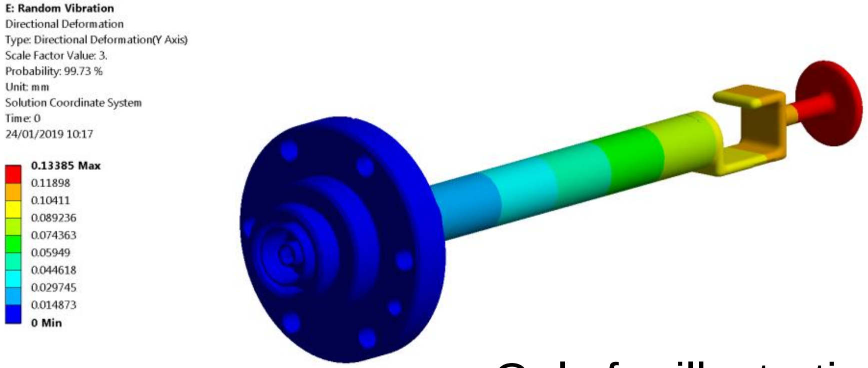
3. Response spectrum analysis

- PSD of the random signal
- Analysis of the response of the model
- A Response PSD is calculated for every node at each frequency.
- A RMS value (1,2 or 3 sigma) for the entire frequency range is calculated for every node

INPUT – ASTM 4169 – Truck PSD



Displacement, 3 sigma



Only for illustration

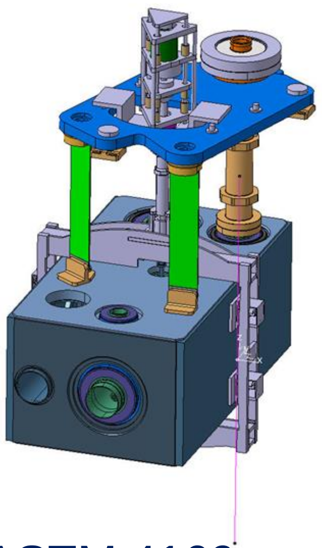
Stress, 3 sigma

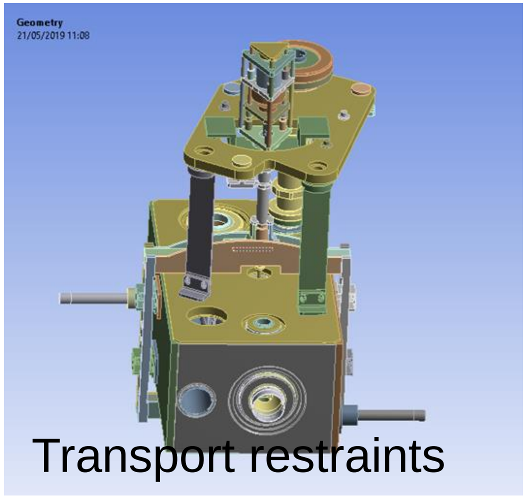
Model validation + component testing

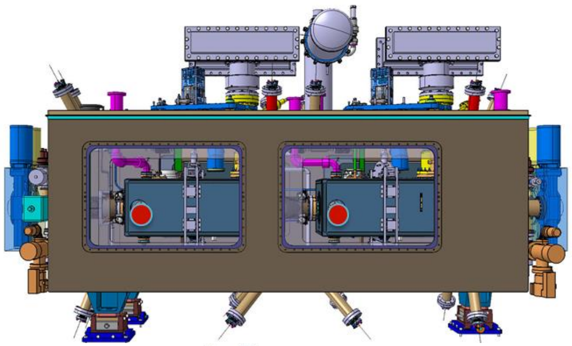
- Comparison with transient analysis
- Shock and random testing on mock up
  - With shaker
  - Drop test
- Component testing possible
- Larger assemblies with analytical models with modal reduction

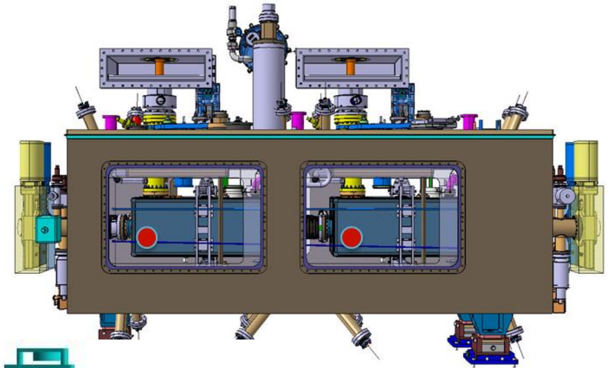
Planned next week

Cavity support

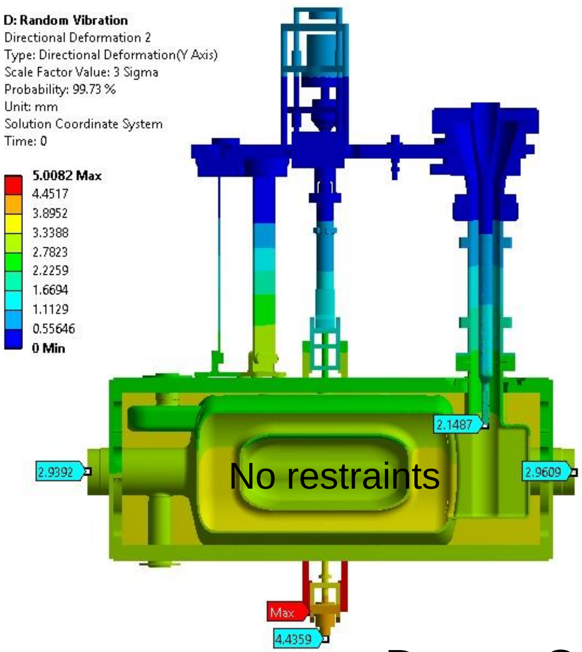


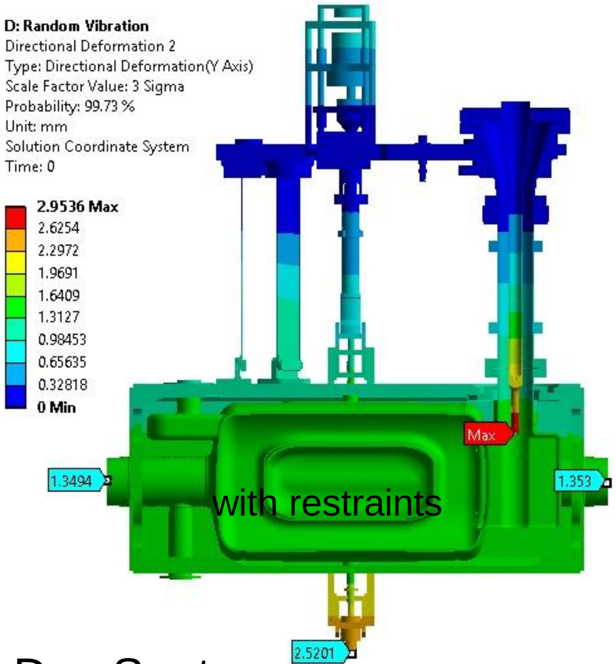






- ASTM 4169 random excitation longitudinal





Preliminary

Cavity support modes

Preliminary

No restraints (Hz) Refined Mesh Model		Staggered restraints (Hz) Refined Mesh Model	
1 Cavity Longitudinal and Lateral	23	51	**1** Cavity Longitudinal
2 Cavity Lateral	25		
3 Cavity Rotation Z	40		
5 FPC Hook Longitudinal	61	61	**3** FPC Hook Longitudinal
6 FPC Hook Lateral	62	61	**4** FPC Hook Lateral
4 Frame Rotation Y	60	57	**2** Frame Rotation Y
7 Motor Lateral	66	66	**5** Motor Lateral
8 Motor Longitudinal	76	77	**6** Motor Longitudinal
10 Cavity Rotation X and Y	100		
9 Frame Rotation X	98	98	**7** Frame Rotation X
11 Frame Rotation Y 2	107	147	**14** Frame Rotation 2 X
12 Cavity Rotation X	111	114	**9** Cavity Rotation X
		128	**11** Frame Diagonal and cavity Rotation X
13 Frame mode diagonal	128	127	**10** Frame Diagonal
14 Frame + outer tube Longitudinal	134	106	**8** Frame + Outer tube
15 Blades	145	143 - 146	**13** + **14 + 15** Blades
		134	**12** Frame Rotation X 2

Transport norms and resources

- ASTM D4169-14 Standard practice for performance testing of shipping containers and systems: Truck update 2016
- MIL-STD-810G Annex : Vibration exposure definition transport
- CTU code

- Consulting agency
- PNNL Nuclear transport
- ESO Transport conditions
- ELI NP Module transport
- Recent TTC
- CERN data
- …

Type of info: Drop test heights, PSD, Intensity acceleration (integrated R.M.S.), «quasistatic», ….

Road transport (g)

	Longit.	Lat.	Vert.
CTU	0.8	0.5	1
Magnuson	2.8 (20 ms)	2.3 (19 ms)	7.0 (77 ms)
NASA	3.5	2.0	6.0
ESO	1	0.6	1.5

Consulting agency: 1.2 g road, 4 g train, 0.8 – 1 g boat, 3 g air

Place your bets… or measure it yourself

Source Tom Nicol talk TTC, shipping of LHC magnets

Significant Recorded Shocks on Magnet							
Magnet	Date	Time (Local)	Location	Lateral	Longitudinal	Vertical	Probable Event
A08	01/18/06	18:01	Baltimore	0.9	1.5	1.6	Handling in shipyard at Baltimore
A08	01/18/06	22:01	Baltimore	1.1	0.9	2.0	Handling in shipyard at Baltimore
A08	01/19/06	2:01	Baltimore	1.3	0.7	1.7	Handling in shipyard at Baltimore
A08	01/19/06	6:01	Baltimore	1.0	1.0	1.9	Handling in shipyard at Baltimore
A08	01/19/06	10:01	Baltimore	0.7	0.8	2.1	Handling in shipyard at Baltimore
A08	01/23/06	22:01	Baltimore	1.8	1.5	1.2	Handling in shipyard at Baltimore
A08	02/02/06	10:01	Baltimore	1.6	1.7	3.8	Loading onto ship
A08	02/09/06	20:01	Antwerp	2.0	1.8	1.7	Unloading from ship
A09	05/08/06	14:29	Fermilab	0.7	0.7	1.5	Truck leaves Fermilab
A09	05/10/06	11:29	Baltimore	1.5	0.7	1.2	Unloading from truck
A09	05/15/06	23:29	Baltimore	0.8	1.4	1.9	Loading onto ship
A09	05/29/06	13:29	Antwerp	1.6	1.6	2.3	Unloading from ship
A09	06/07/06	13:29	CERN	0.9	2.0	11.9	Arrival at CERN (possibly recorders removed)
B06	01/25/06	12:31	Baltimore	1.2	1.3	2.6	Handling in shipyard at Baltimore
B06	02/02/06	8:31	Baltimore	0.3	0.9	0.5	Loading onto ship
B06	02/16/06	7:31	Antwerp	1.6	1.2	1.6	Unloading from ship
B06	02/20/06	15:31	Antwerp	1.5	1.5	1.7	Handling in shipyard at Antwerp
B06	02/20/06	19:31	Antwerp	2.2	1.1	1.2	Handling in shipyard at Antwerp
B06	02/22/06	15:31	CERN	2.1	10.1	6.8	Arrival at CERN (possibly recorders removed)
B10	04/08/06	11:33	Baltimore	0.8	0.7	1.5	Unloading from truck
B10	04/13/06	10:53	Baltimore	0.6	1.0	1.0	Loading onto ship
B10	04/27/06	10:53	Antwerp	0.8	0.5	0.6	Unloading from ship
B10	05/02/06	18:53	Antwerp	3.0	1.4	1.1	Handling in shipyard at Antwerp
B10	05/04/06	2:53	Geneva	2.1	0.7	0.1	Truck enroute to CERN
B11	03/05/07	11:27	Fermilab	1.5	1.3	1.3	Truck enroute to airport
B11	03/05/07	12:27	Fermilab	1.3	1.3	1.3	Truck enroute to airport
B11	03/07/07	13:27	CERN	2.3	3.2	11.8	Arrival at CERN (possibly recorders removed)
C05	02/14/06	12:34	Baltimore	0.8	0.6	1.2	Arrival in shipyard at Baltimore
C05	03/02/06	16:34	Baltimore	2.4	1.1	2.1	Loading onto ship
C05	03/18/06	10:34	Antwerp	1.1	0.7	1.5	Unloading from ship
C06	01/09/06	7:31	Fermilab	1.2	1.4	0.6	Loading onto truck
C06	01/10/06	16:31	Baltimore	4.3	2.1	1.7	Arrival in shipyard at Baltimore
C06	01/11/06	12:31	Baltimore	1.8	10.2	1.6	Handling in shipyard at Baltimore
C06	02/02/06	12:31	Baltimore	1.1	1.0	1.1	Loading onto ship
C06	02/09/06	18:31	Antwerp	1.7	0.7	1.1	Unloading from ship
C06	02/10/06	18:31	Antwerp	1.0	0.9	1.3	Handling in shipyard at Antwerp
C07	03/16/06	11:25	Baltimore	1.1	1.4	2.3	Loading onto ship
C07	03/30/06	13:25	Antwerp	2.0	1.6	1.7	Unloading from ship
C07	04/04/06	17:25	Antwerp	1.3	1.2	1.0	Loading onto truck
C07	04/06/06	9:25	CERN	1.4	2.8	8.0	Arrival at CERN (possibly recorders removed)
C08	05/04/06	11:54	Baltimore	1.3	2.3	0.9	Handling in shipyard at Baltimore
C08	05/04/06	15:54	Baltimore	1.7	1.2	1.0	Handling in shipyard at Baltimore
C08	05/19/06	9:54	Antwerp	1.5	1.9	1.6	Unloading from ship
C08	05/22/06	21:54	Antwerp	0.7	1.5	1.1	Loading onto truck
C08	05/24/06	9:54	CERN	1.3	2.2	1.1	Arrival at CERN
C09	09/25/06	17:22	Chicago	0.7	2.2	2.4	Truck enroute to Baltimore
C09	09/25/06	21:22	Chicago	1.7	4.8	4.7	Truck enroute to Baltimore
C09	09/26/06	22:22	Baltimore	0.5	0.9	1.6	Arrival at shipyard in Baltimore
C09	09/29/06	22:22	Baltimore	1.1	1.1	2.4	Loading onto ship

[red] Recorded shocks in excess of 2 g.

[orange] Questionable data. May have occurred after recorders removed.

Note: Indicated times are end of a 4-hour sampling window.
Recorded values are peak values recorded during the 4-hour period.
Exception is B11. Sampling period is 30 minutes (shipped by air).

Talk Edward Jordan

Thank you for your attention!

HiLumi
HL-LHC PROJECT

Spare slides

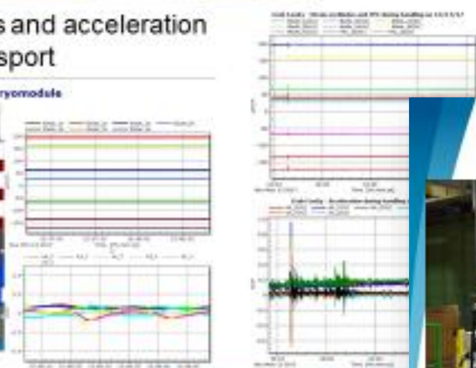
Ad-Hoc Measurements

Ad-Hoc Measurement: RF & Transport

Radiofrequency performance monitored during all major steps

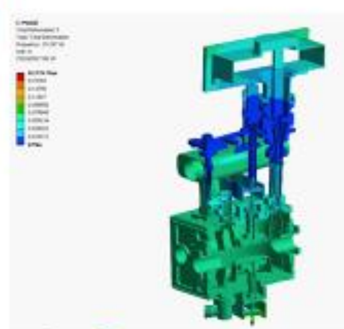
- Acceptance
- Tuner Assy
- Connection to to Vessel
- Coax lines + Assy
- Closure

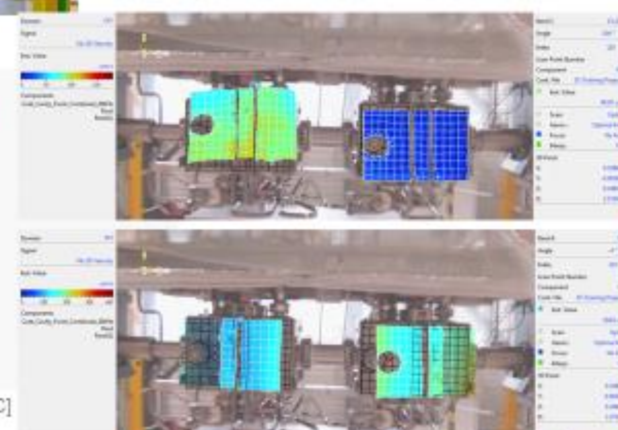
Structural loading of cavity supports and acceleration monitored during assembly and transport



Ad-Hoc Measurement: Vibrational

- Vibrometry acquisition via 3D Laser Scanning
- Configuration: hanging top cover and cavity string
- Comparison ongoing between FE analysis and measured data





Courtesy T. Jones [STFC]

Road transport				
Securing in	**Acceleration coefficients**			
	Longitudinally (c_x)		Transversely (c_y)	Minimum vertically down (c_z)
	forward	rearward		
Longitudinal direction	0.8	0.5	-	1.0
Transverse direction	-	-	0.5	1.0

Rail transport (combined transport)				
Securing in	**Acceleration coefficients**			
	Longitudinally (c_x)		Transversely (c_y)	Minimum vertically down (c_z)
	forward	rearward		
Longitudinal direction	0.5 (1.0)†	0.5 (1.0)†	-	1.0 (0.7)†
Transverse direction	-	-	0.5	1.0 (0.7)†

† **The values in brackets apply to shock loads only with short impacts of 150 milliseconds or shorter, and may be used, for example, for the design of packaging.**

Sea transport					
Significant wave height in sea area		**Securing in**	**Acceleration coefficients**		
			Longitudinally (c_x)	Transversely (c_y)	Minimum vertically down (c_z)
A	$H_s \leq 8$ m	Longitudinal direction	0.3	-	0.5
		Transverse direction	-	0.5	1.0

Sea transport					
Significant wave height in sea area		**Securing in**	**Acceleration coefficients**		
			Longitudinally (c_x)	Transversely (c_y)	Minimum vertically down (c_z)
B	$8 \text{ m} < H_s \leq 12$ m	Longitudinal direction	0.3	-	0.3
		Transverse direction	-	0.7	1.0
C	$H_s > 12$ m	Longitudinal direction	0.4	-	0.2
		Transverse direction	-	0.8	1.0

5.4 The effect of short term impact or vibrations should always be considered. Therefore, whenever the cargo cannot be secured by blocking, lashing is required to prevent the cargo from being significantly displaced, taking into account the characteristics of the cargo and the mode of transport. The mass of the cargo alone, even when combined with a high friction coefficient (see appendix 2 to annex 7), does not sufficiently secure the cargo as the cargo can move due to vibrations.

5.5 The significant 20-years return wave height (H_s) is the average of the highest one-third of waves (measured from trough to crest) that is only exceeded once in 20 years. The allocation of geographic sea areas to the respective significant wave heights is shown in the following table:

A	B	C
$H_s \leq 8$ m	$8 \text{ m} < H_s \leq 12$ m	$H_s > 12$ m
Baltic Sea (incl. Kattegat) Mediterranean Sea Black Sea Red Sea Persian Gulf Coastal or inter-island voyages in following areas: Central Atlantic Ocean (between 30°N and 35°S) Central Indian Ocean (down to 35°S) Central Pacific Ocean (between 30°N and 35°S)	North Sea Skagerak English Channel Sea of Japan Sea of Okhotsk Coastal or inter-island voyages in following areas: South-Central Atlantic Ocean (between 35°S and 40°S) South-Central Indian Ocean (between 35°S and 40°S) South-Central Pacific Ocean (between 35°S and 45°S)	unrestricted

Sources:
The Royal Netherlands Meteorological Institute (KNMI):
The KNMI/ERA-40 Wave Atlas, derived from 45 years of ECMWF reanalysis data (ed. S.Caires, A.Stern, G.Komen and V.Swail), last updated 2011,
Hs 100-yr return values, 1958 – 2000

Shipping Weight, lb (kg)	Drop Height, in. (mm) Assurance Level I	II	III
0 to 20 (0 to 9.1)	24 (610)	15 (381)	9 (229)
20 to 40 (9.1 to 18.1)	21 (533)	13 (330)	8 (203)
40 to 60 (18.1 to 27.2)	18 (457)	12 (305)	7 (178)
60 to 80 (27.2 to 36.3)	15 (381)	10 (254)	6 (152)
80 to 100 (36.3 to 45.4)	12 (305)	9 (229)	5 (127)
100 to 200 (45.4 to 90.7)	10 (254)	7 (178)	4 (102)

Number of Impacts at Specified Height	Impact Orientation - First Sequence of Distribution Cycle: Box	Bag or Sack	Cylindrical Container
One	top	face	top
Two	adjacent bottom edges	two sides	two sides 90° apart
Two	diagonally opposite bottom corners	both ends	bottom edges 90° apart
One	bottom	opposite face	bottom

Number of Impacts at Specified Height	Impact Orientation - Second Sequence of Distribution Cycle: Box	Bag or Sack	Cylindrical Container
One	vertical edge	face	top
Two	adjacent side faces	two sides	two sides 90° apart
Two	one top corner and one adjacent top edge	both ends	bottom edges 90° apart
One	see Note 1	see Note 1	see Note 1

NOTE 1—On the last impact of the last manual handling sequence in a distribution cycle, the impact should be made at *twice* the specified height or equivalent velocity change. (This is the final (sixth) drop in the sequence, not an additional drop.) The drop should be in the impact orientation most likely for a drop to occur, usually the largest face or the bottom. For distribution cycles where any drop orientation is possible (that is, shipments via carriers that mechanically sort packages), this drop should be in the most critical or damage-prone orientation, as defined in Test Method D5276.

NOTE 2—The equivalent velocity change corresponding to the specified drop height used for the shock machine method shall be calculated as specified in Test Method D5487.

10.3.1.1 *Fork Lift Truck Handling*—One rotational flat drop from each opposite base edge in accordance with Method C of Test Methods D6179 and one rotational drop on each of two diagonally opposite base corners in accordance with Method B of Test Methods D6179.

Gross Weight, lb (kg)	Drop Height, in. (mm) Assurance Level I	II	III
0 to 500 (0 to 226.8)	12 (305)	9 (229)	6 (152)
Over 500 (226.8)	9 (229)	6 (152)	3 (076)

10.3.1.2 *Crane Handling*—(Conduct this test only if cranes are used for handling in the distribution process.) One drop flat on bottom and one drop on base edge in accordance with Method D of Test Methods D6179. Use the same drop heights versus shipping unit weight as in 10.3.1.1.

Table 2-4. Summary of Shock Data

Carrier	Axis	Peak Acceleration (g)	Pulse Duration (ms)
Truck (shocks superimposed on vibration)	Longitudinal	2.8	20
	Transverse	2.3	19
	Vertical	7.0	77
Rail (shocks superimposed on vibration)	All	4.7	14
Rail coupling[a] (11.05 mph)	Longitudinal	39.0	18
	Vertical	26.0	9
Source: Magnuson and Wilson (1977) a. Based on ATMX railcar with 5-ton cargo.			

Table 2-1. Truck Vibration Data

Frequency Band (Hz)	Measurements on Cargo Floor (g) 99% Level of Zero to Peak Amplitude		
	Longitudinal Axis	Transverse Axis	Vertical Axis
0-5	0.10	0.10	2.0
5-10	0.08	0.06	1.04
10-20	0.84	0.15	1.68
20-40	0.51	0.24	1.20
40-80	0.36	0.42	0.50
80-120	0.24	0.27	0.87
120-180	1.23	0.21	0.63
180-240	0.87	0.12	0.87
240-350	0.24	0.15	0.63
350-500	0.24	0.15	0.42
500-700	0.87	0.15	0.87
700-1000	1.50	0.87	1.17
1000-1400	0.87	1.17	1.17
1400-1900	0.39	0.24	0.87
Source: Magnuson and Wilson (1977)			

TABLE 1. – TRANSPORTATION LIMIT LOAD FACTORS
[From ref. 15]

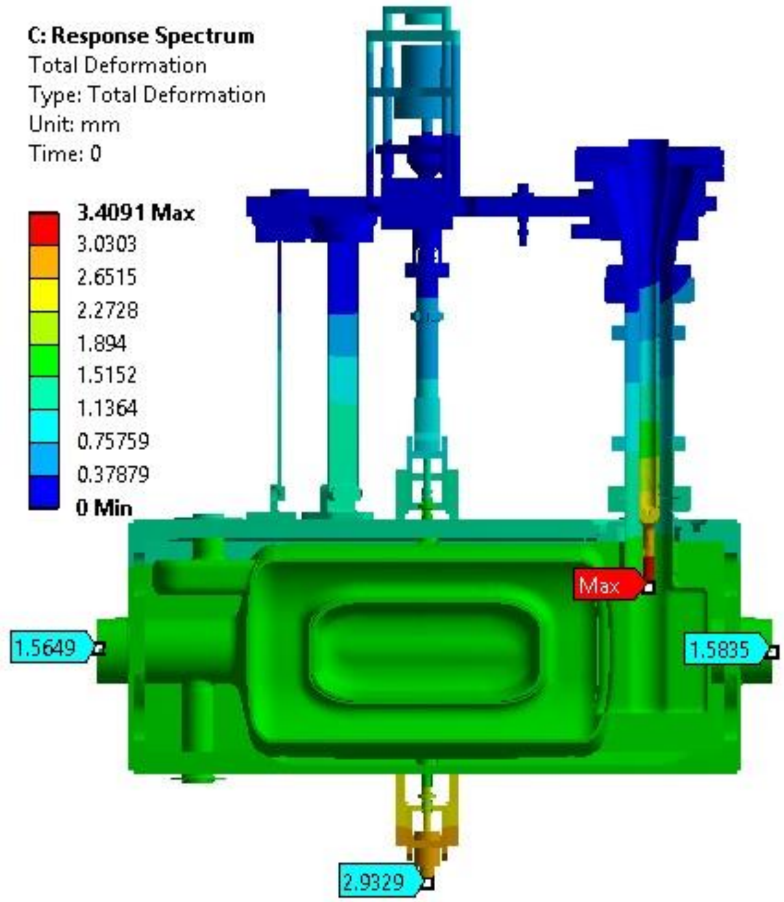
NASA

Medium/mode	Longitudinal load factors, g	Lateral load factors, g	Vertical load factors, g
Water	±0.5	±2.5	+2.5
Air	±3.0	±1.5	±3.0
Ground			
Truck	±3.5	±2.0	+6.0
Rail (humping shocks)	±6.0 to ±30.0	±2.0 to ±5.0	+4.0 to +15.0
Rail (rolling)	±0.25 to ±3.0	±0.25 to ±0.75	+0.2 to +3.0
Slow-moving dolly	±1.0	±0.75	+2.0

Response Spectrum Analysis vs. Static Structural

Response Spectrum Analysis

- 10G shock, 20ms and 1% damping (Y Direction)



Static Structural

- 10G acceleration (Y Direction)