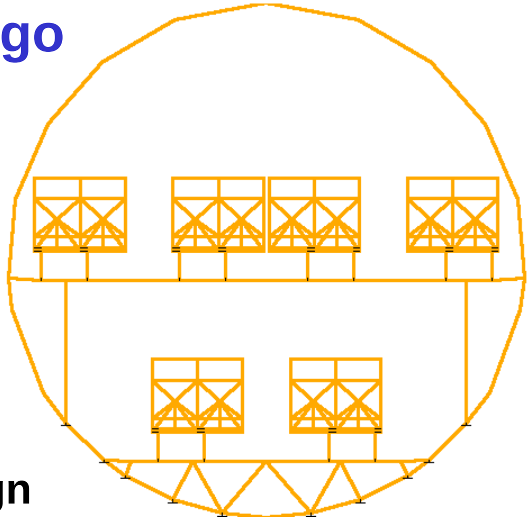
Studies about the Utilisation of the Aircraft Cargo Compartment as additional Passenger Cabin by Use of Numerical Crash Simulation



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Atlantic City, USA, October 29 – November 1, 2007

Outline of Presentation

- Introduction
- Set-up of DRI-KRASH Models
- Lower Deck Seating (LDS) – Parametric Study
- Assessment of Occupant Safety
  in different LDS Configurations => BASE Criteria
- Proposed LDS Configuration
- Conclusions

The work presented here is part of the project "Innovative Cabin Technologies" (KATO) which was funded by the German Federal Ministry of Economics and Technology – Reference No. 20K0302V

Introduction

The worldwide growth in air transportation as well as the need of further reductions in the specific fuel consumption requires a more efficient use of aircraft.

The use of sections of the cargo compartment as additional passenger cabin space could increase the passenger capacity of wide-body aircraft.

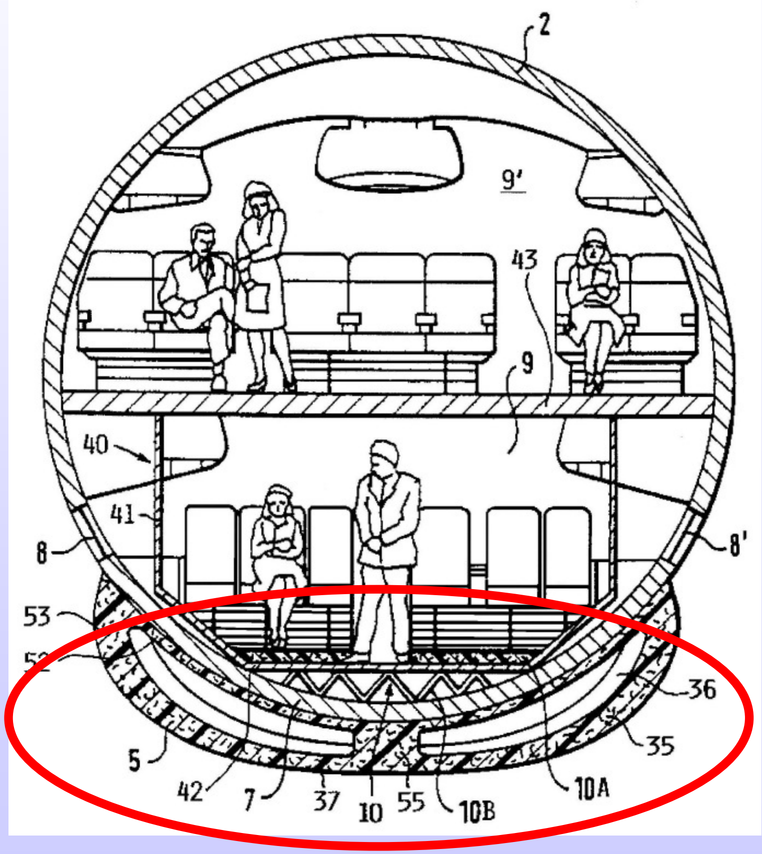
The primary aspect of 'Lower Deck Seating' (LDS) is the safety of the passengers, which – in case of a crash landing – should be comparable to the passenger safety on the main deck.

In order to assess the occupant safety and the feasibility of LDS, DLR developed the concept of the 'BASE Criteria'.

Different LDS / fuselage design concepts were analysed with the hybrid crash simulation program DRI-KRASH and finally the most promising configuration chosen.

Lower Deck Seating – Airbus / Boeing Patents

U.S. Patent No. 5,542,626 / 1996 – Beuck et al. (Airbus)



Energy absorbing structural unit attached to the fuselage underside

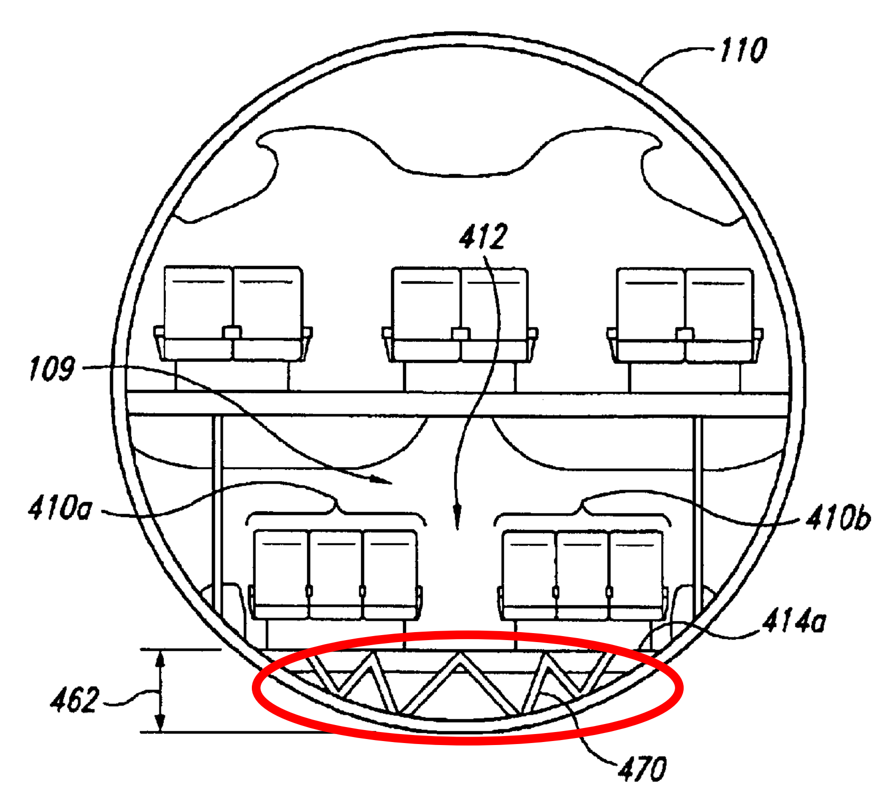
Advantage:
Accelerations may be within acceptable limits

Disadvantage:
Additional weight and drag => higher fuel consumption

Remark: After an estimation of the extra weight, this concept was not considered in the here presented work.

Lower Deck Seating – Airbus / <u>Boeing</u> Patents

U.S. Patent No. 6,772,977 B2 / 2004
– Dees et al. (Boeing)



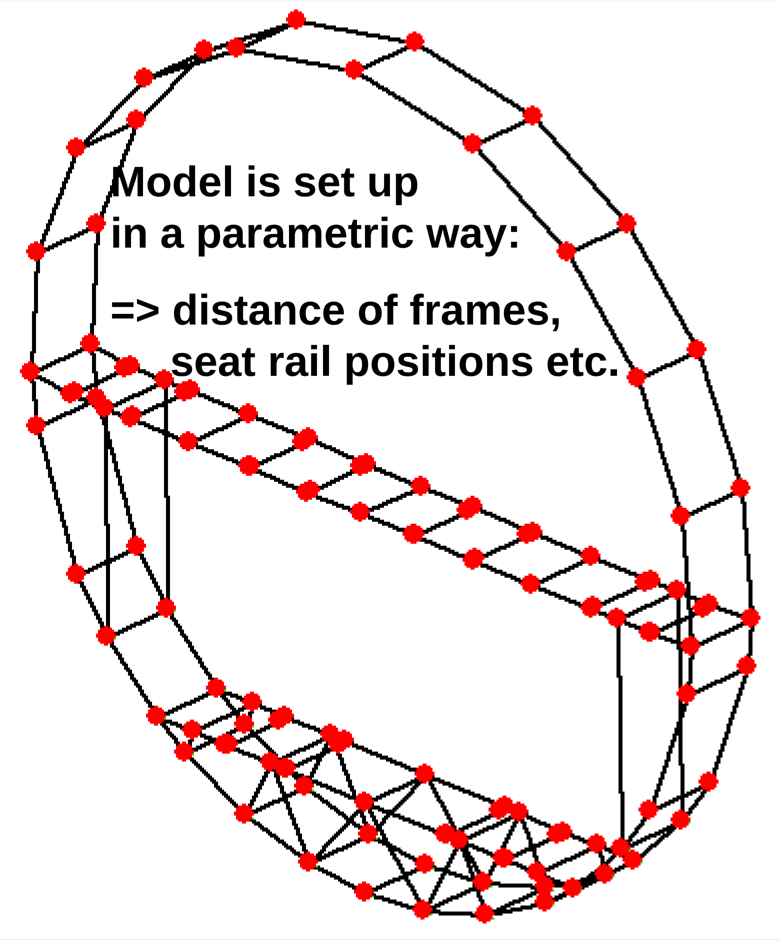
Energy absorbing structure ('470') below lower floor, within original fuselage contour

Advantage:
Only little additional weight, no additional drag

Possible disadvantage:
Accelerations may be relatively high (to be analysed)

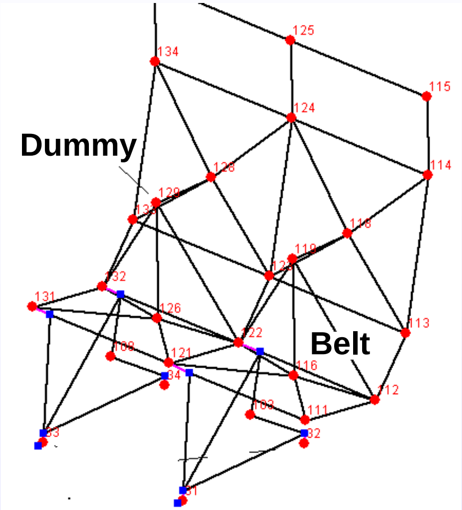
Set-up of the DRI-KRASH Models

Fuselage Section Model

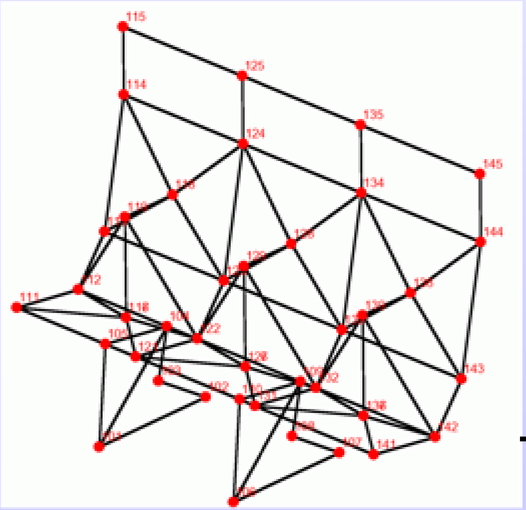


Model is set up in a parametric way:

=> distance of frames, seat rail positions etc.



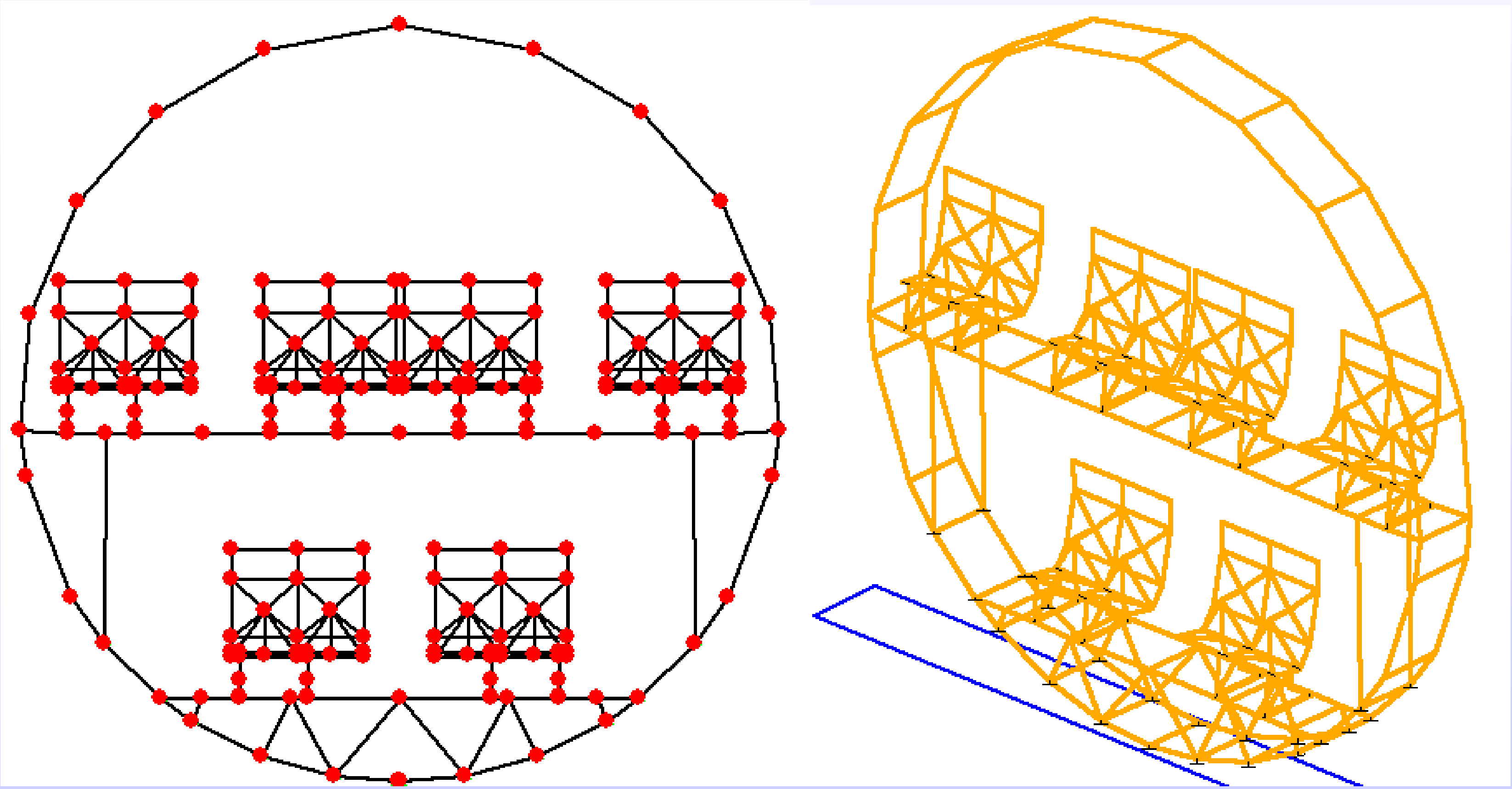
Double Seat Model



Triple Seat Model

Set-up of the DRI-KRASH Models

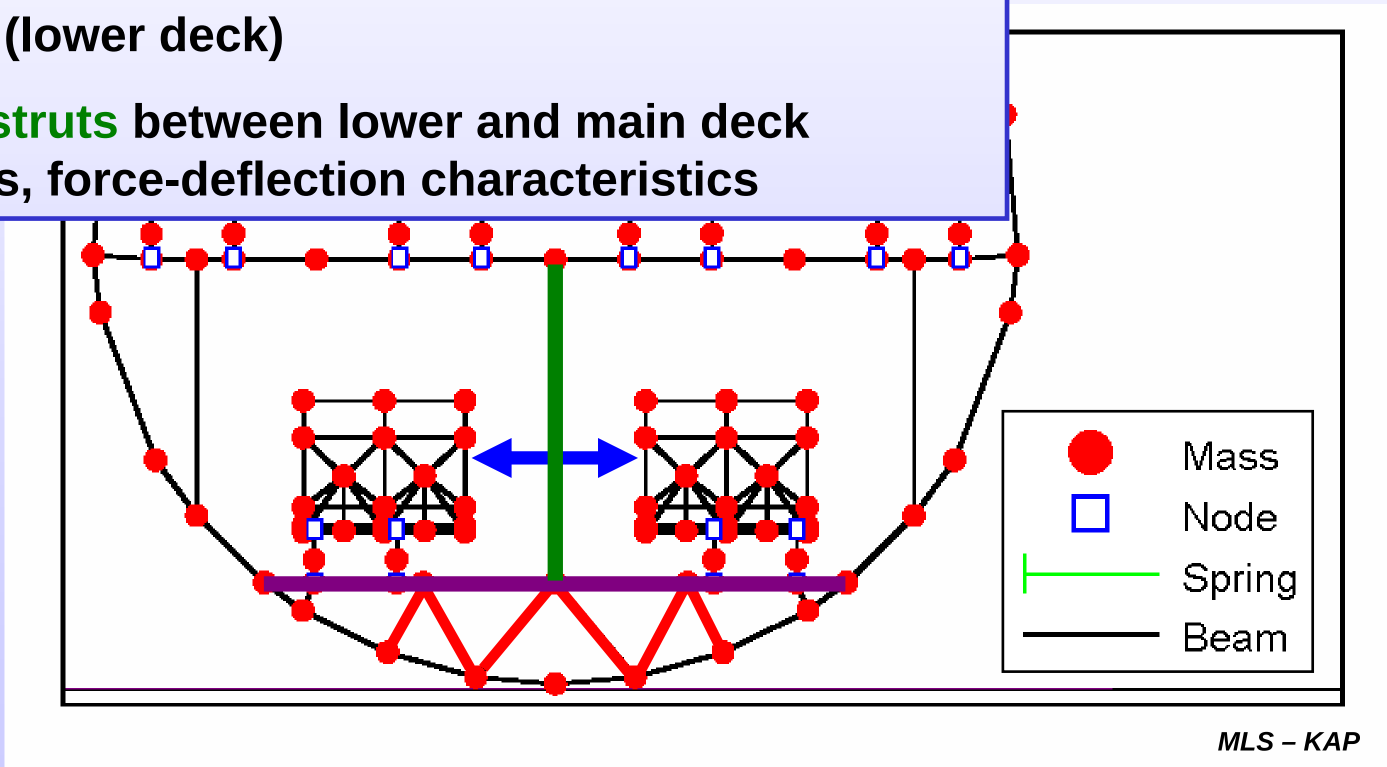
Basic configuration with 8 seats on the main deck and 4 seats on the lower deck



LDS Parametric Study

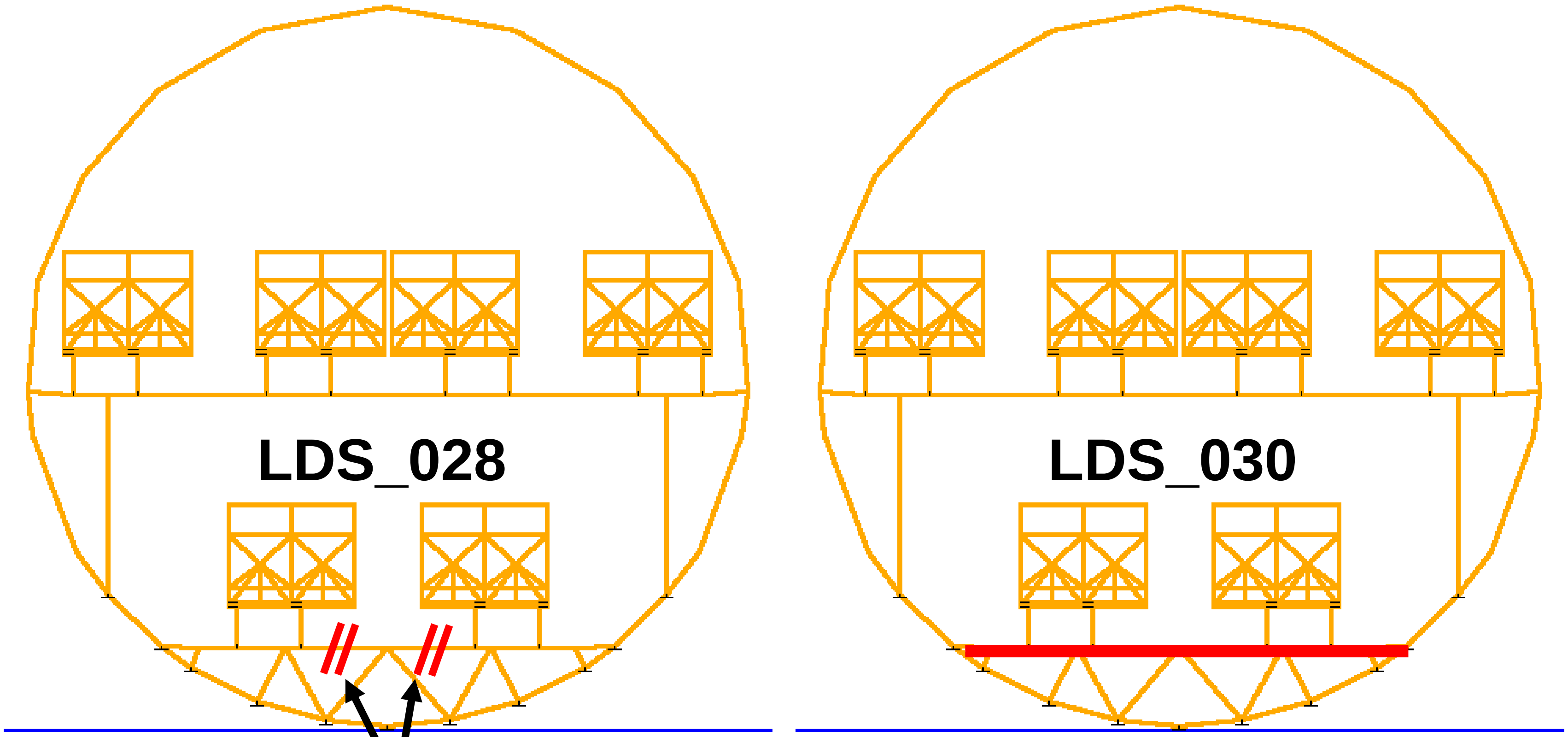
Varied Parameters

- Properties of lower deck floor cross beams
- force-deflection characteristics of energy absorbing lower deck floor struts
- Aisle width (lower deck)
- Additional struts between lower and main deck
  => positions, force-deflection characteristics



Comparison of 2 LDS Configurations

Vertical impact speed: 6.7 m/s (22 ft/s) in all simulations presented here

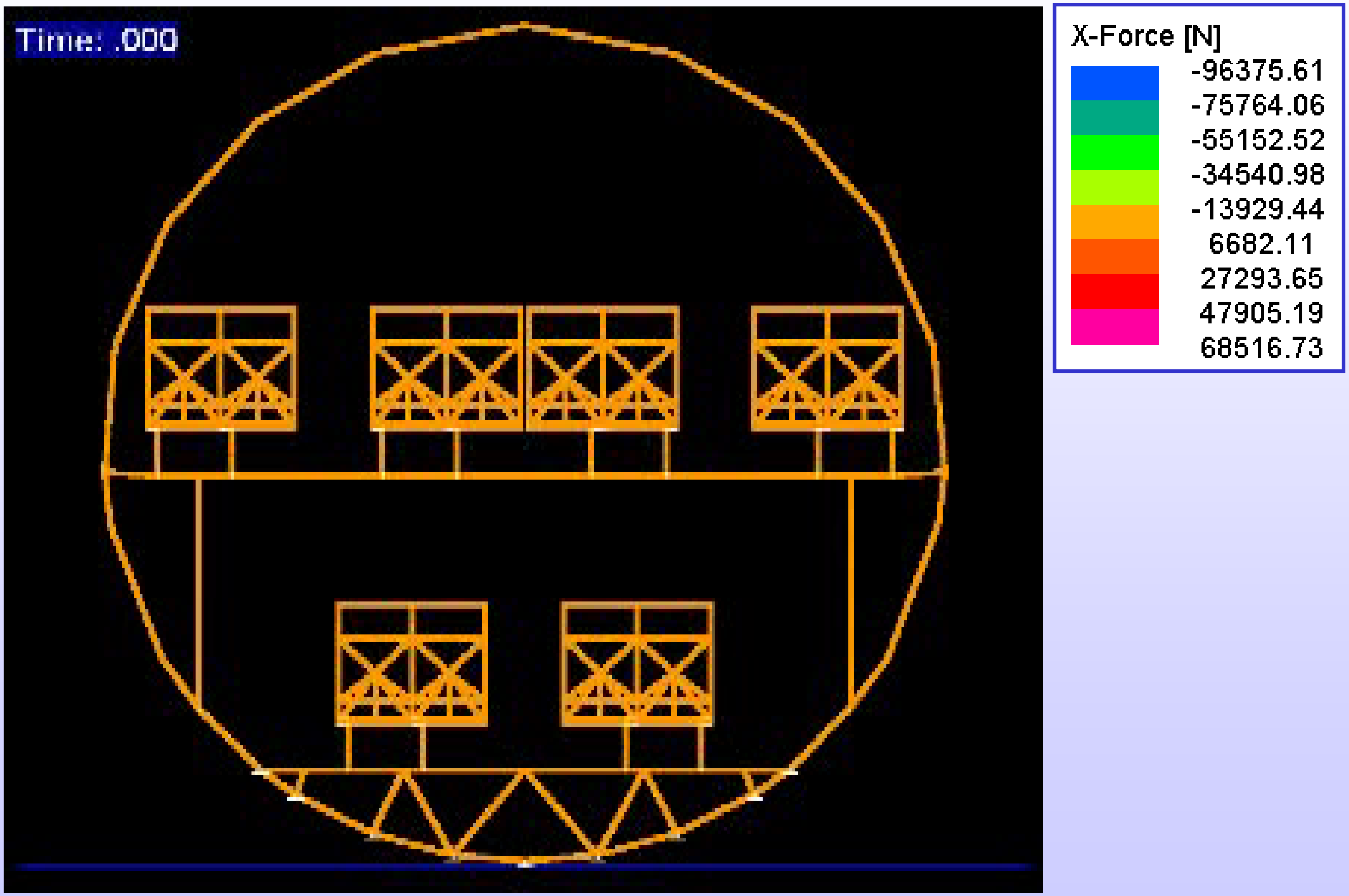


Possible rupture of lower floor

No failure (stiffened cross beams)

Comparison of 2 LDS Configurations

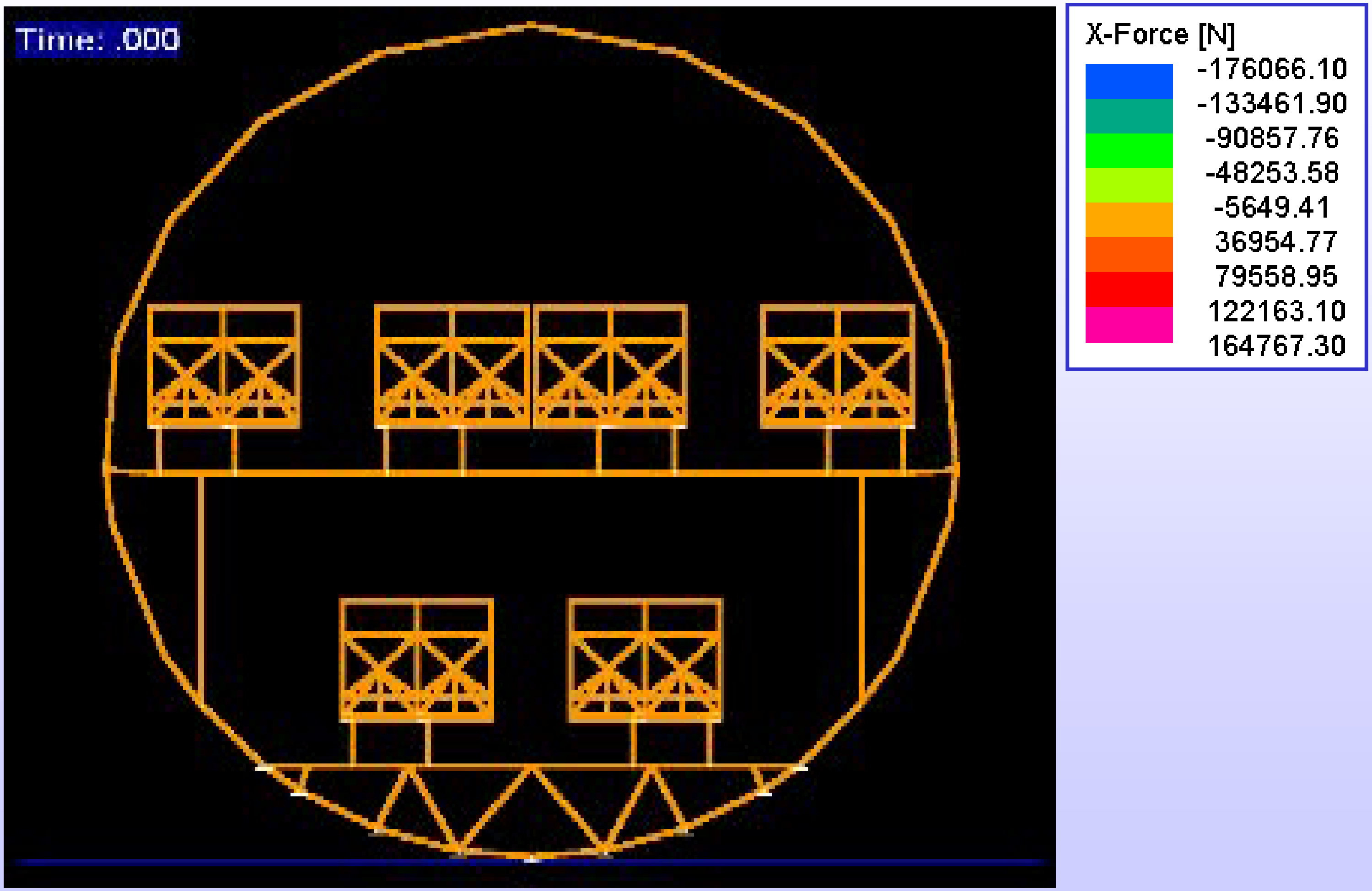
With rupture of lower floor cross beams



DLR_L028f_KAP.avi ***KAP*** **– KRASH Animation Program**

Comparison of 2 LDS Configurations

No failure of lower floor cross beams (stiffened)



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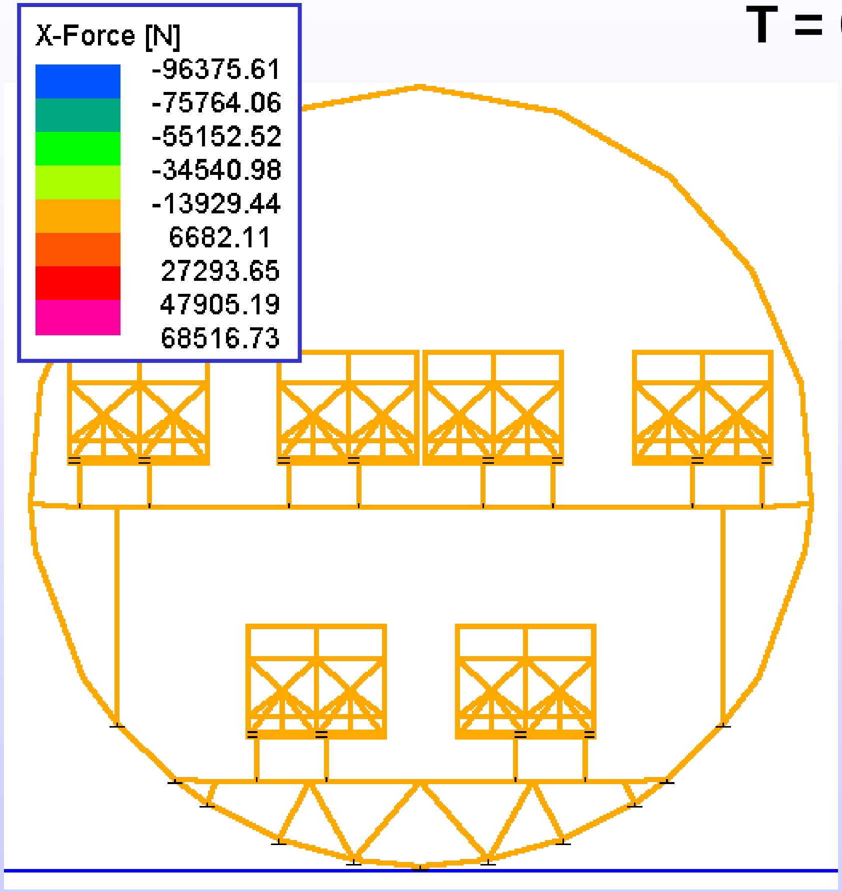
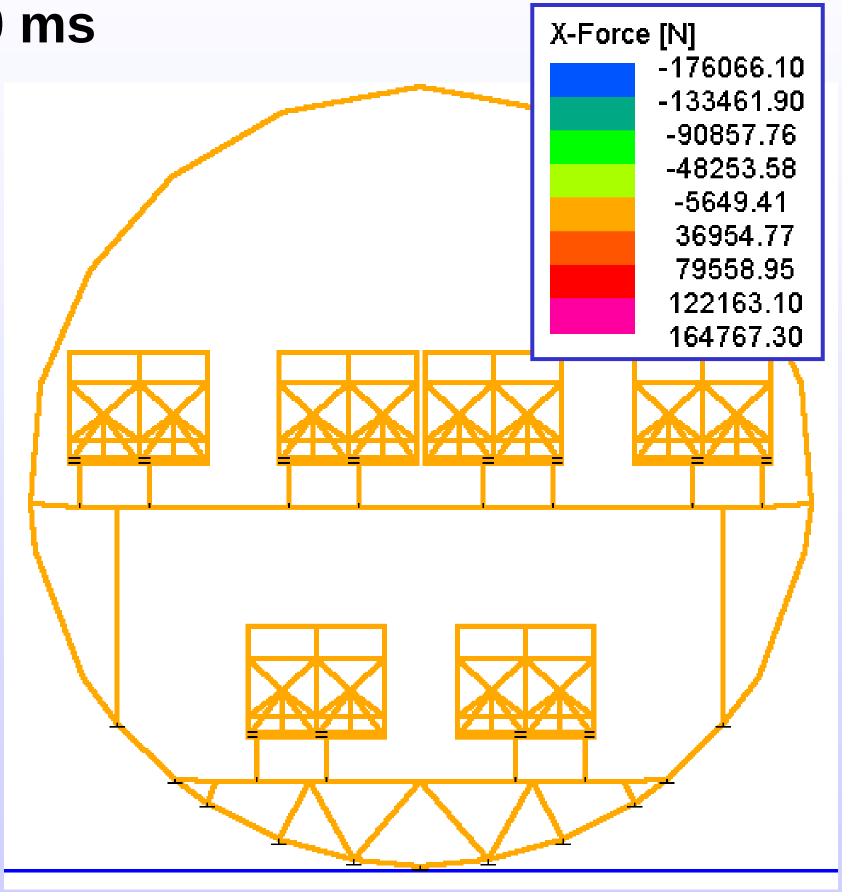
***KAP* – KRASH Animation Program**

Comparison of 2 LDS Configurations

T = 0 ms



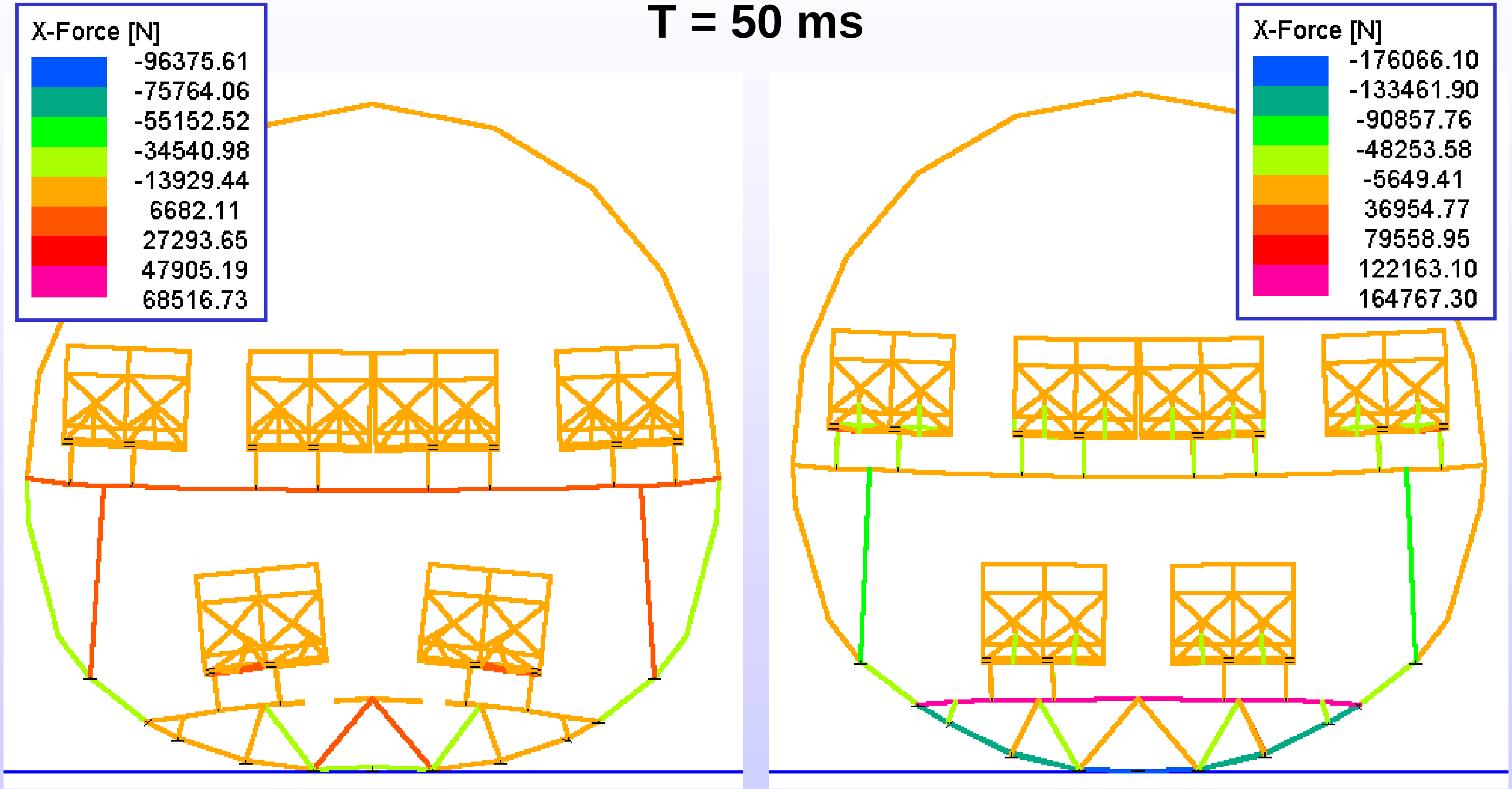
With rupture of lower floor cross beams



No failure of lower floor cross beams

Comparison of 2 LDS Configurations

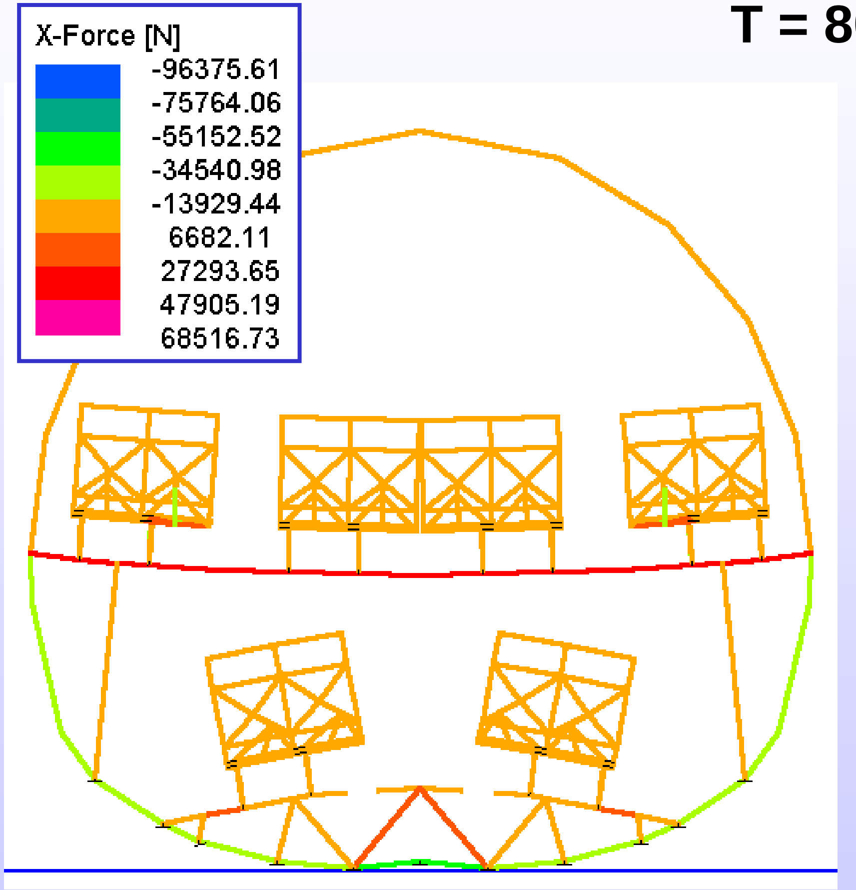
T = 50 ms



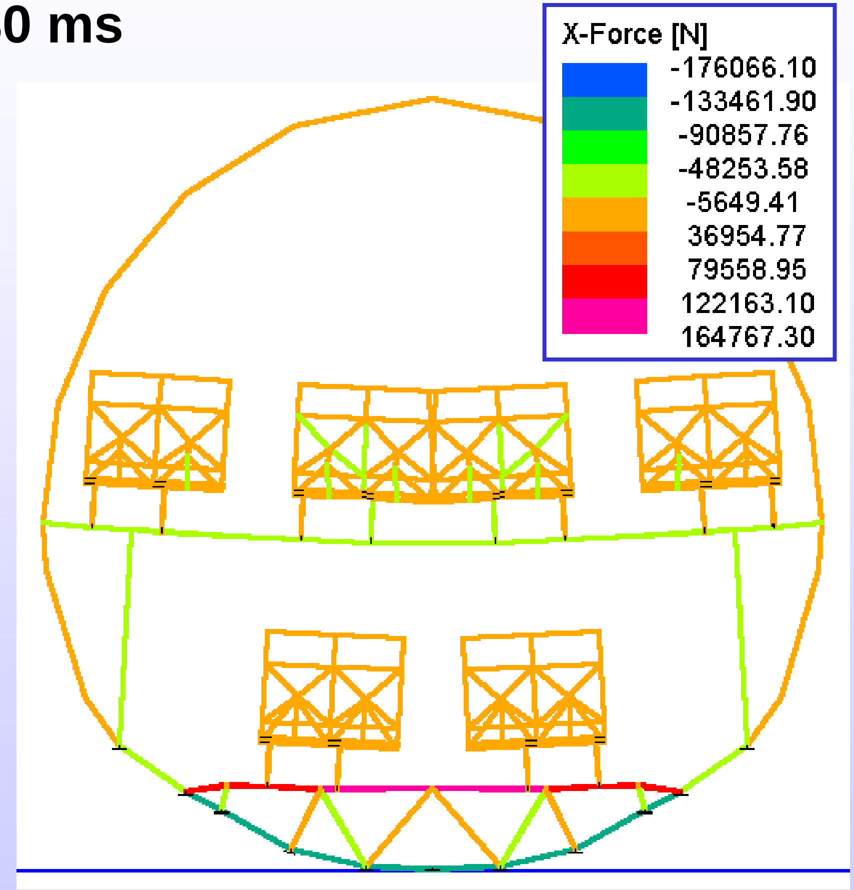
With rupture of lower floor cross beams **No failure of lower floor cross beams**

Comparison of 2 LDS Configurations

T = 80 ms



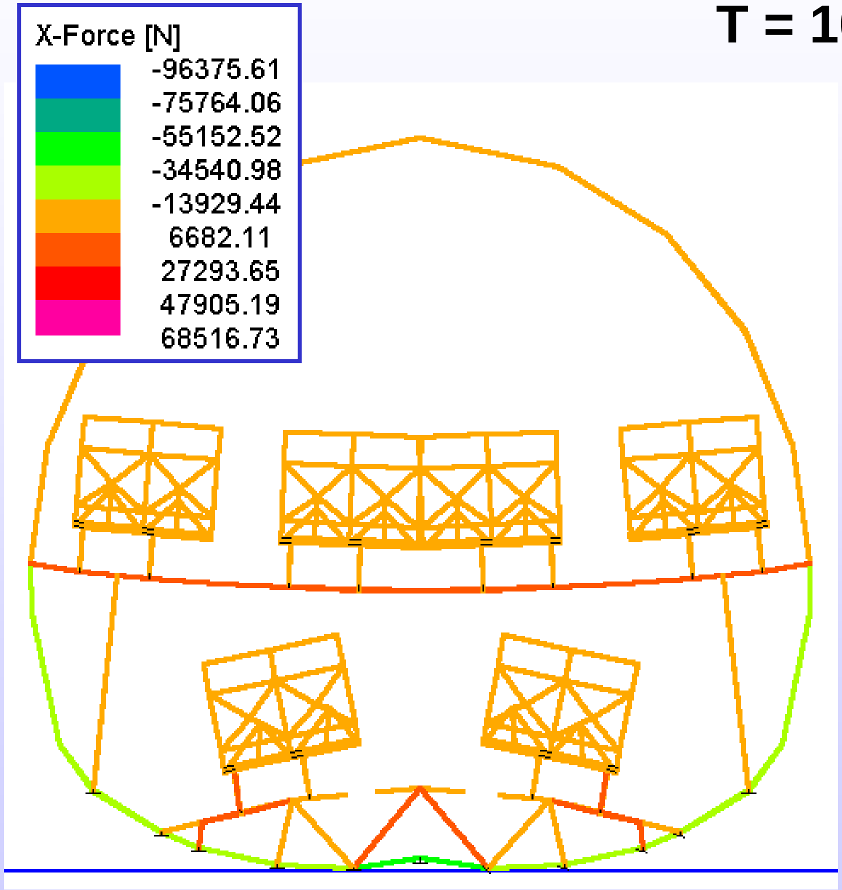
With rupture of lower floor cross beams



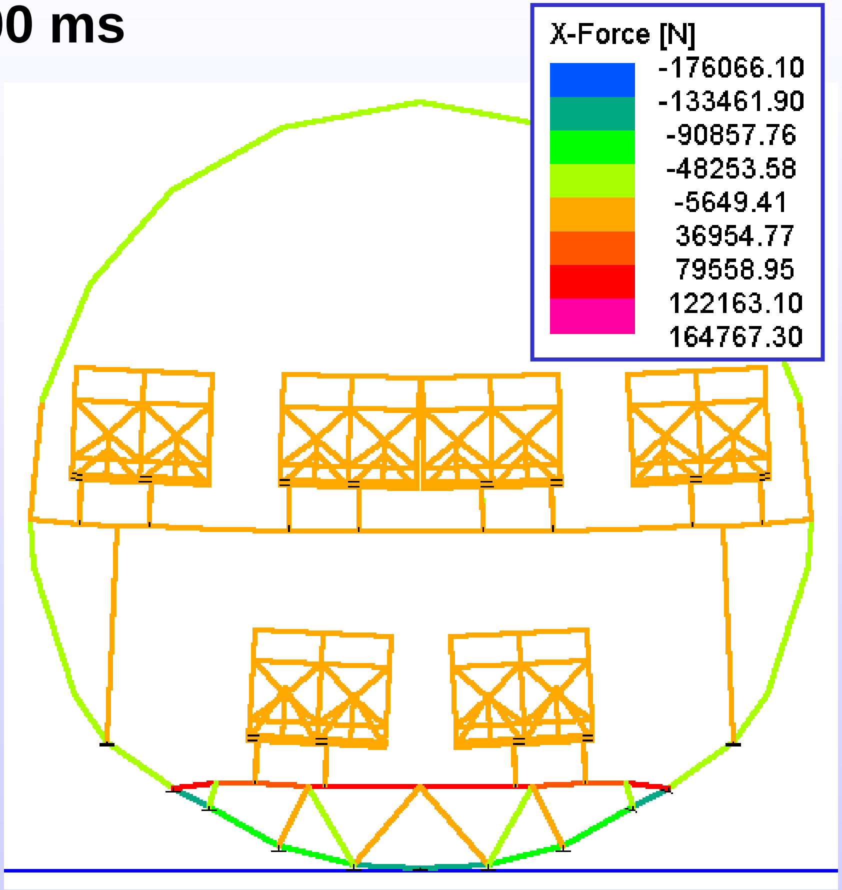
No failure of lower floor cross beams

Comparison of 2 LDS Configurations

T = 100 ms



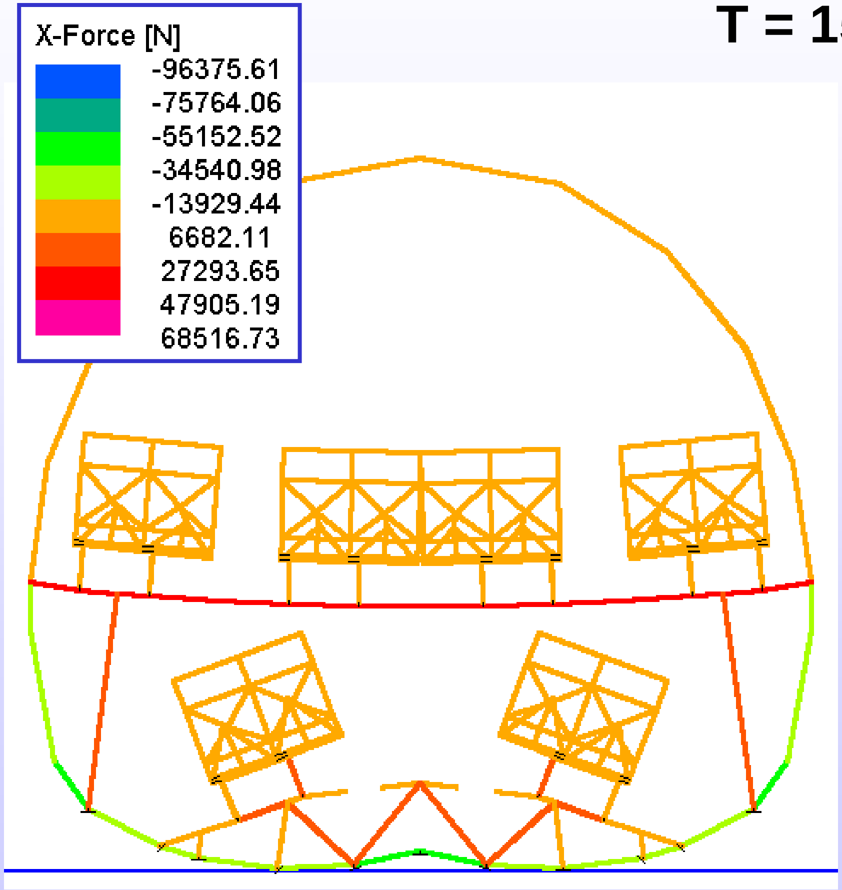
With rupture of lower floor cross beams



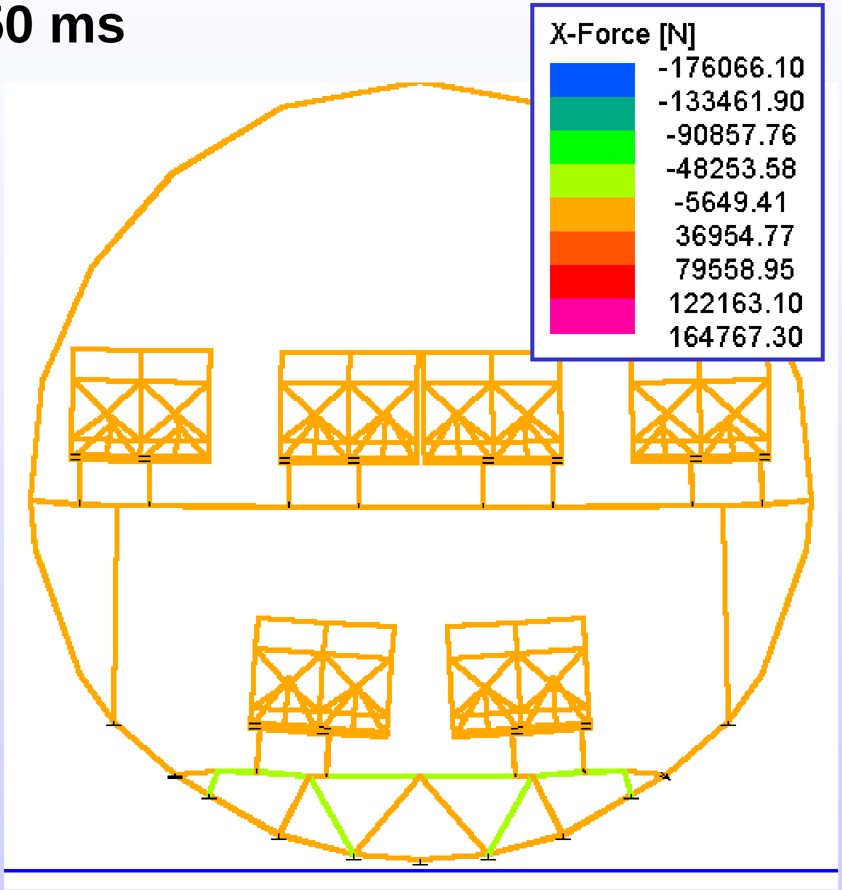
No failure of lower floor cross beams

Comparison of 2 LDS Configurations

T = 150 ms

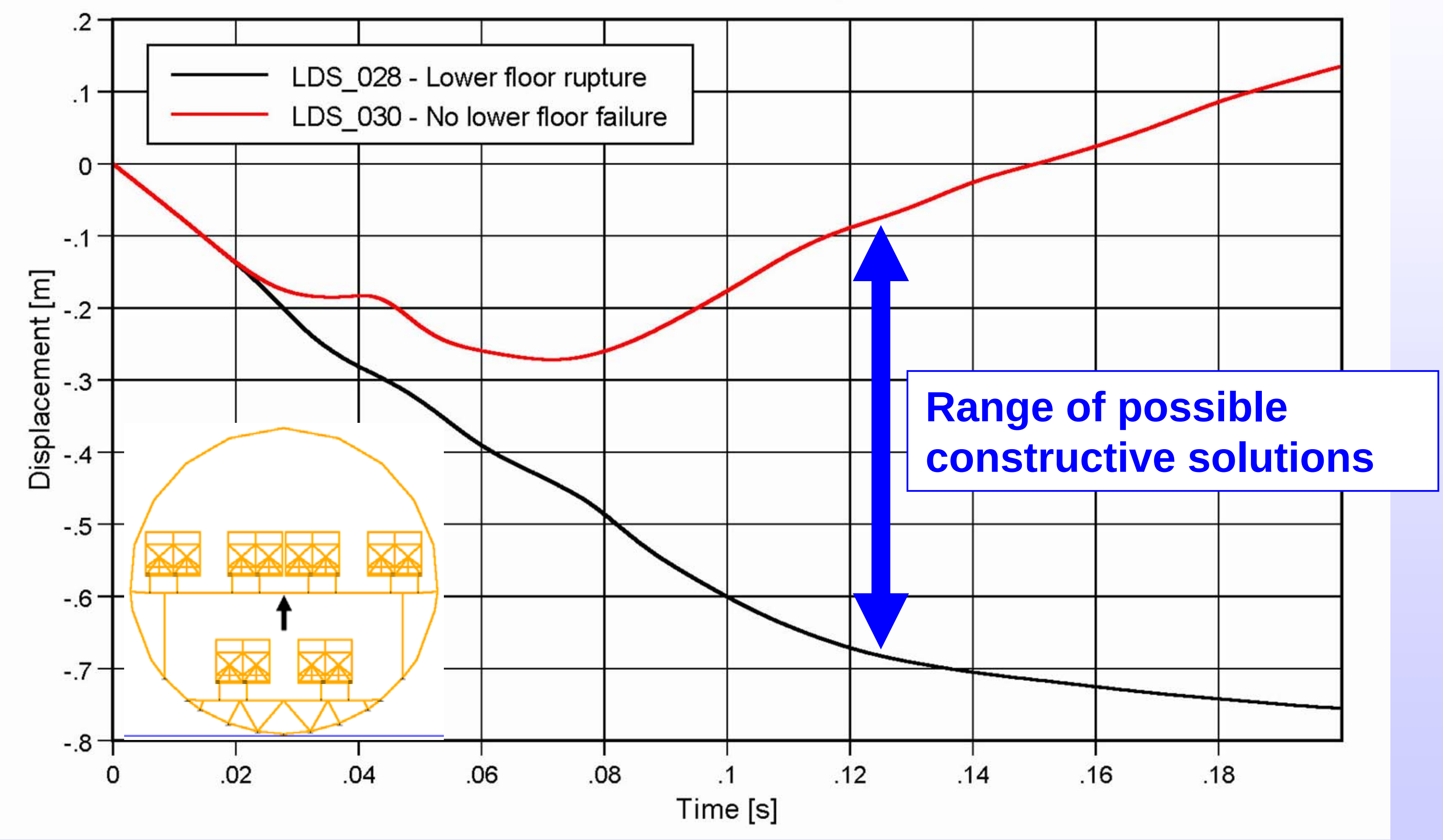


With rupture of lower floor cross beams

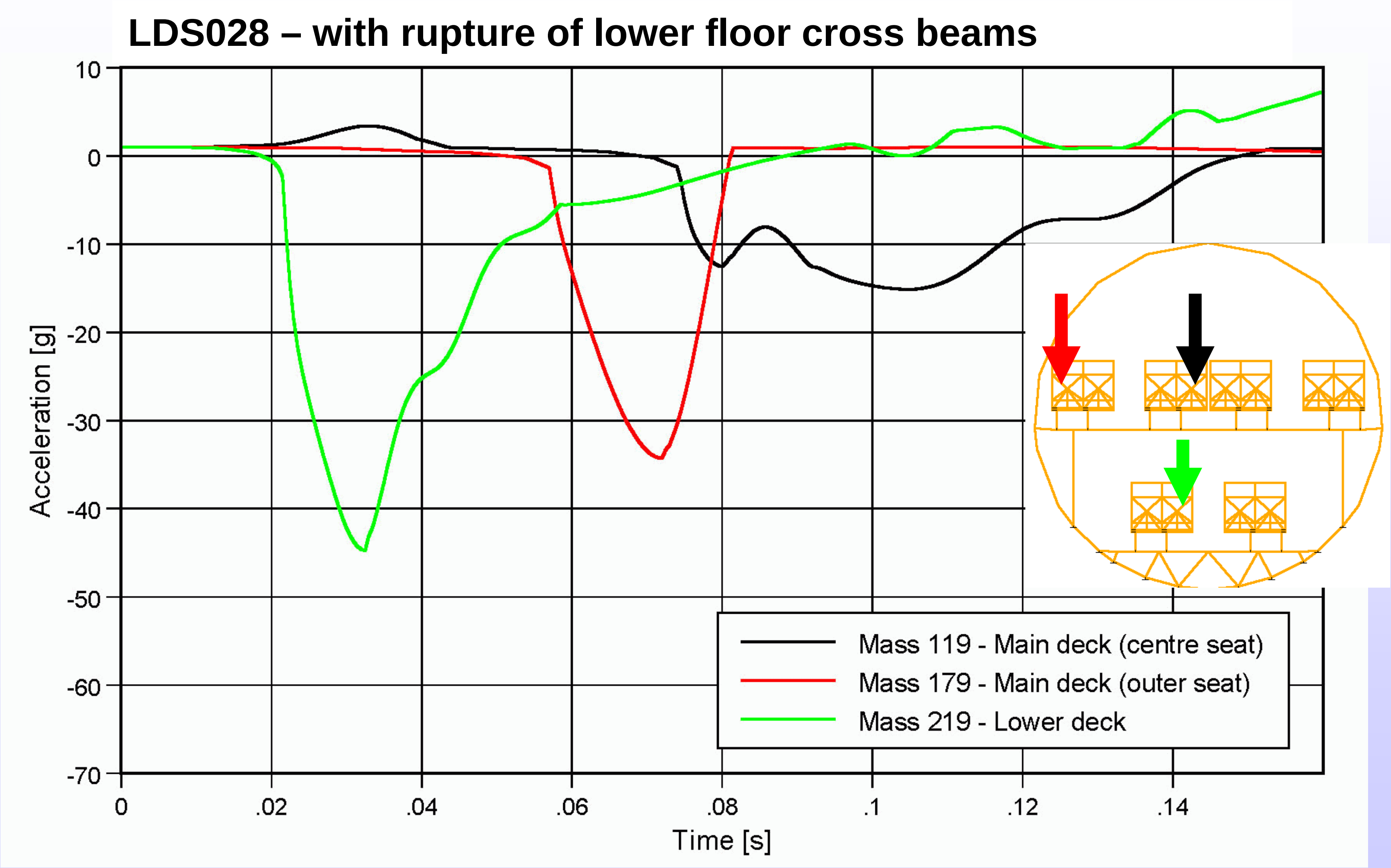


No failure of lower floor cross beams

Vertical displacement of floor centre (main deck)

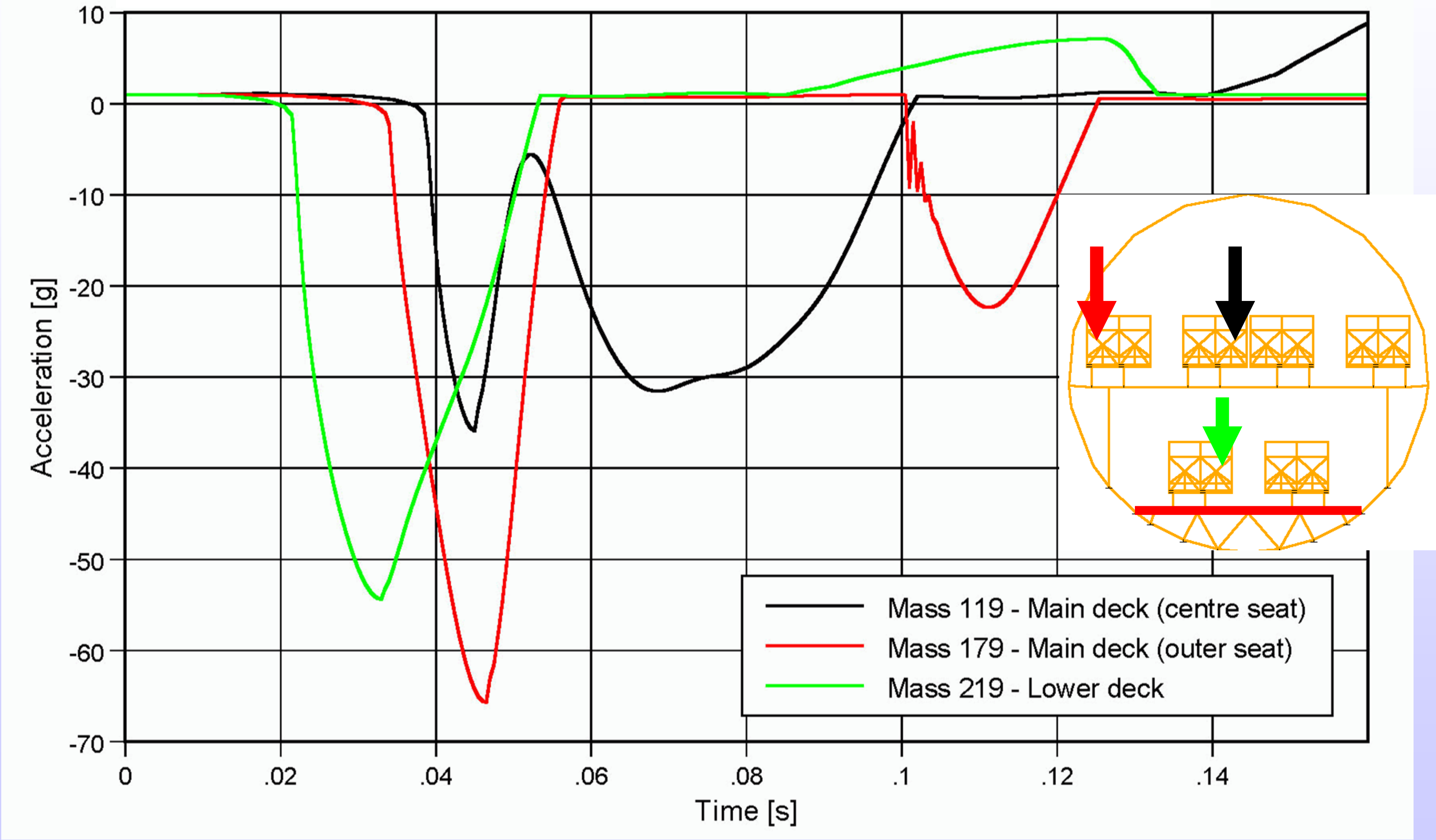


Comparison of z-accelerations at 3 seat positions

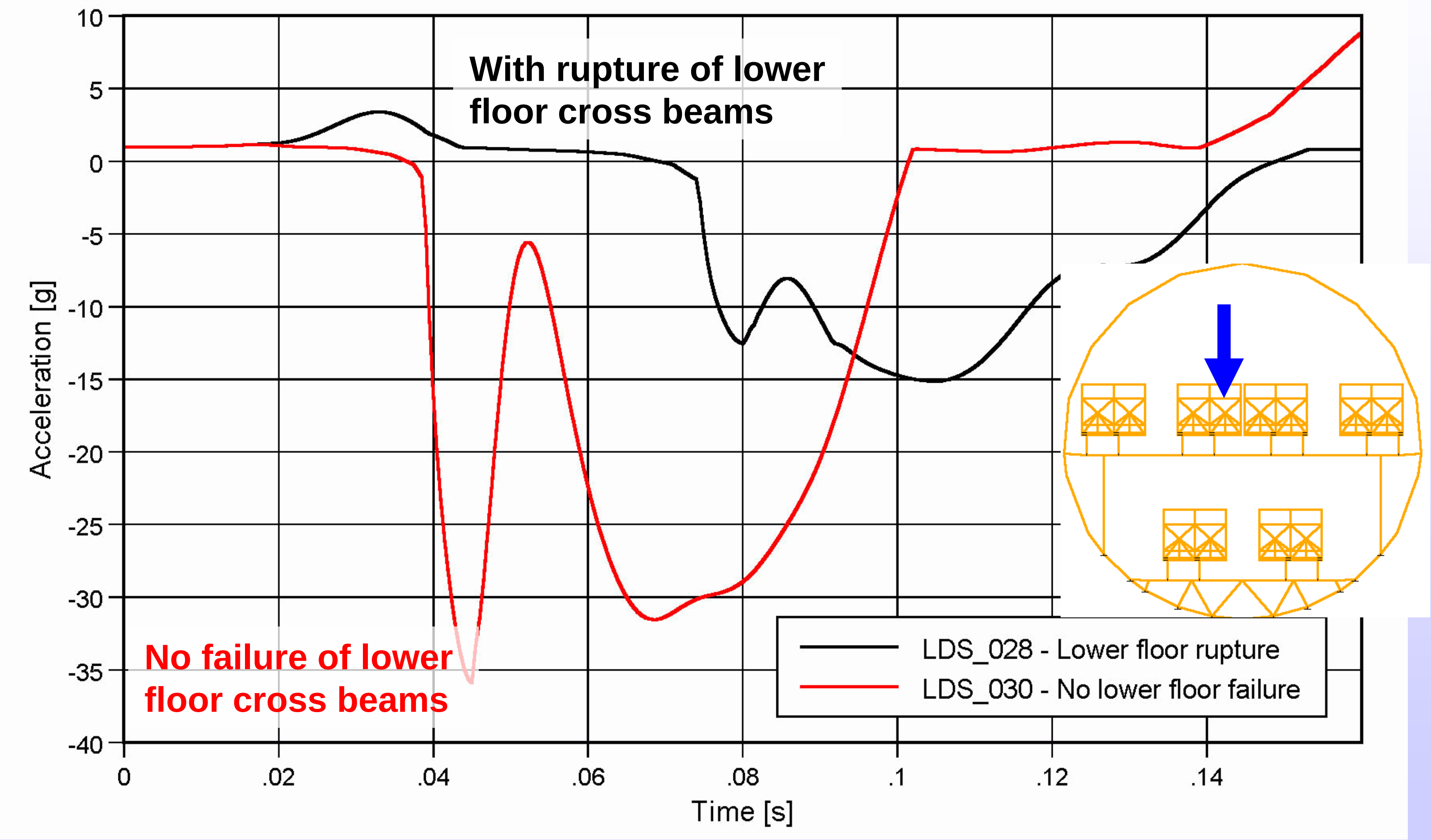


Comparison of z-accelerations at 3 seat positions

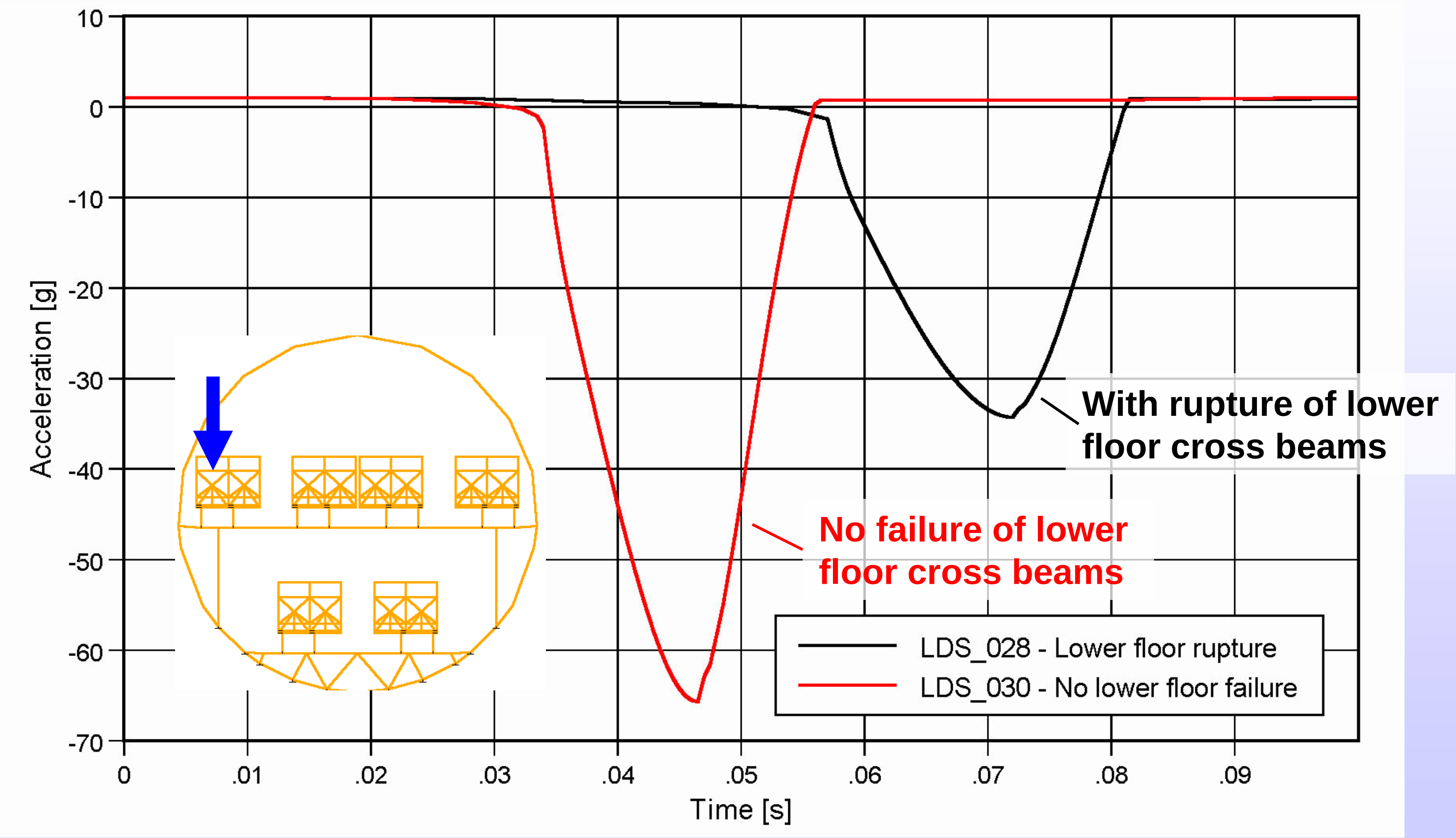
LDS030 – with stiffened lower floor cross beams



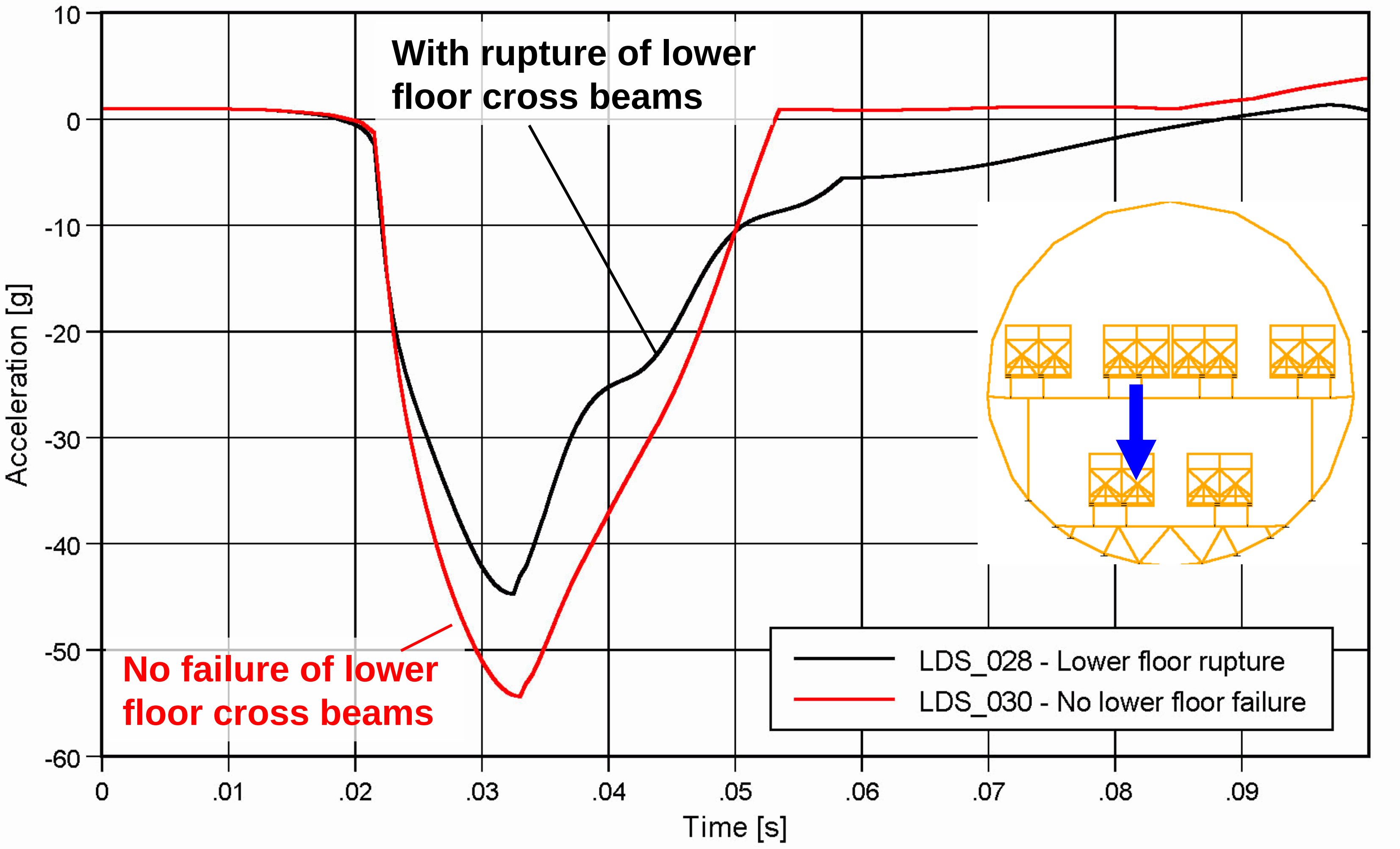
Passenger z-accelerations – Main deck centre seat



Passenger z-accelerations – Main deck outer seat



Passenger z-accelerations – Lower deck



Assessment of Occupant Safety in different LDS Configurations

BASE – Criteria	
Overhead **B**in	150 points
Acceleration	500 points
Survival **S**pace	250 points
Escape Route	100 points
Maximum achievable: 1000 points	

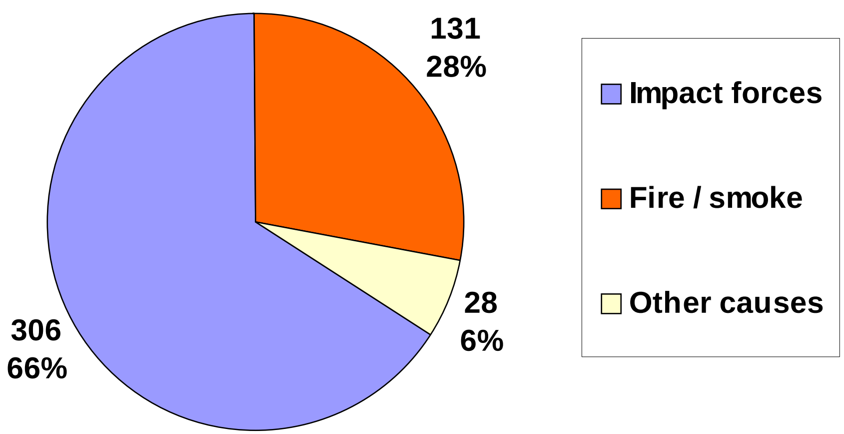
The safety potential of each LDS configuration (and each seat) is judged on the basis of a point scheme, which assesses the following 4 criteria: Accelerations, preservation of a living space, injury risk from falling objects (e.g. overhead bins or hand luggage) and sustainment of an escape route. The evaluation scheme thus includes the entire occupant environment.

The BASE Criteria are used to compare different configurations and seat positions, not to give an exact "safety mark" or to predict a certain injury level!

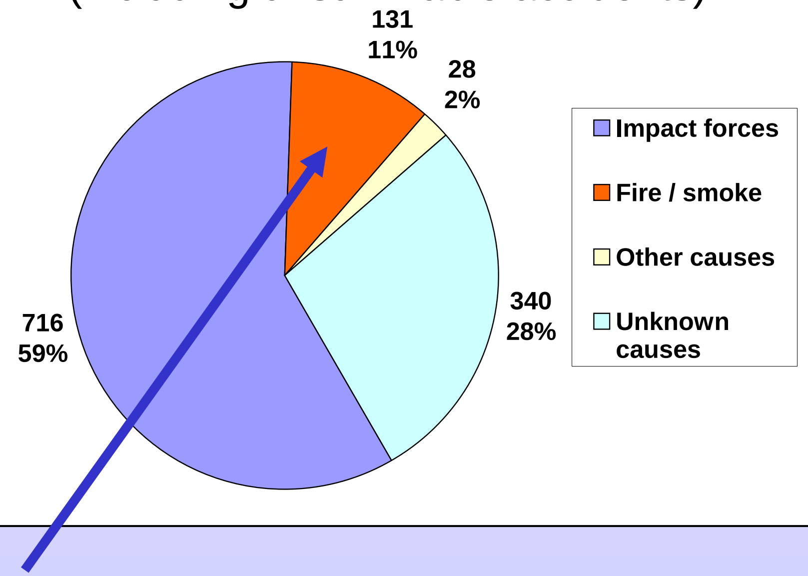
Fatalities in aircraft accidents (NTSB Study)

“Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983 through 2000”, Safety Report NTSB/SR-01/01, March 2001

Fatalities in survivable accidents



Fatalities in all serious accidents
(including unsurvivable accidents)

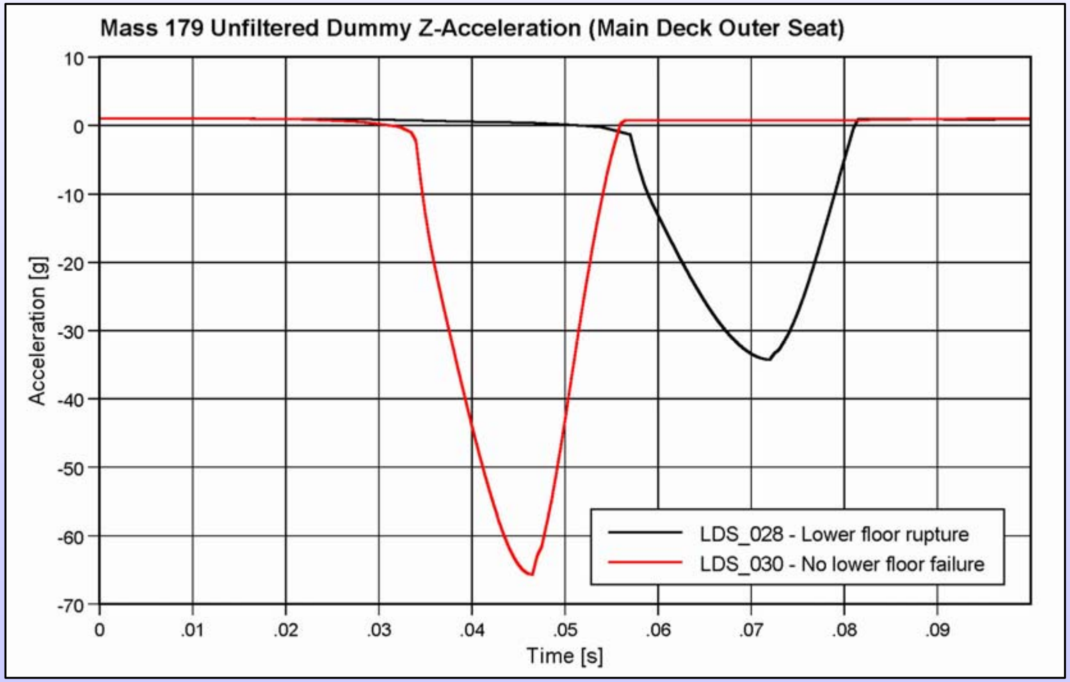


Even if the risk of fire/smoke cannot be calculated with a crash simulation code, this risk is partly considered in the BASE criterion ‘Escape Route’.

Assessment of Occupant Safety in different LDS Configurations

BASE – Criterion 'Acceleration' => max. 500 points (50%)

- **Includes risk of spinal injury or failure (break away) of seat etc.**
- **Different sub-criteria may be used: e.g. Dynamic Response Index DRI, lumbar spine load criterion, EIBAND diagrams ...**



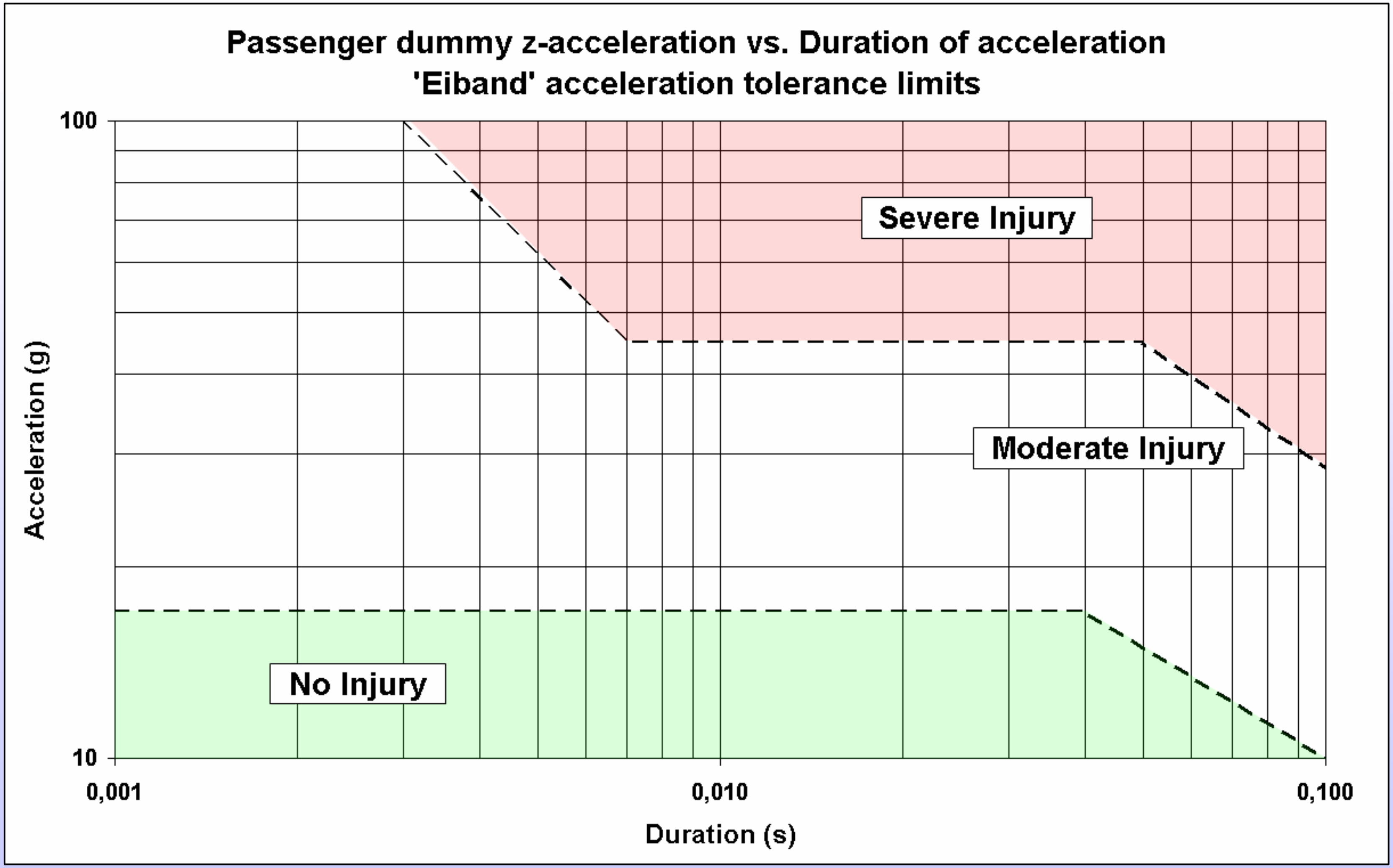
EIBAND evaluation of acceleration pulses

- Eiband diagrams depict magnitude of acceleration versus the duration of acceleration on a logarithmic scale.
- developed by Martin Eiband (NASA)
- used to ascertain the extensiveness of injury to passengers
- based on experimental results

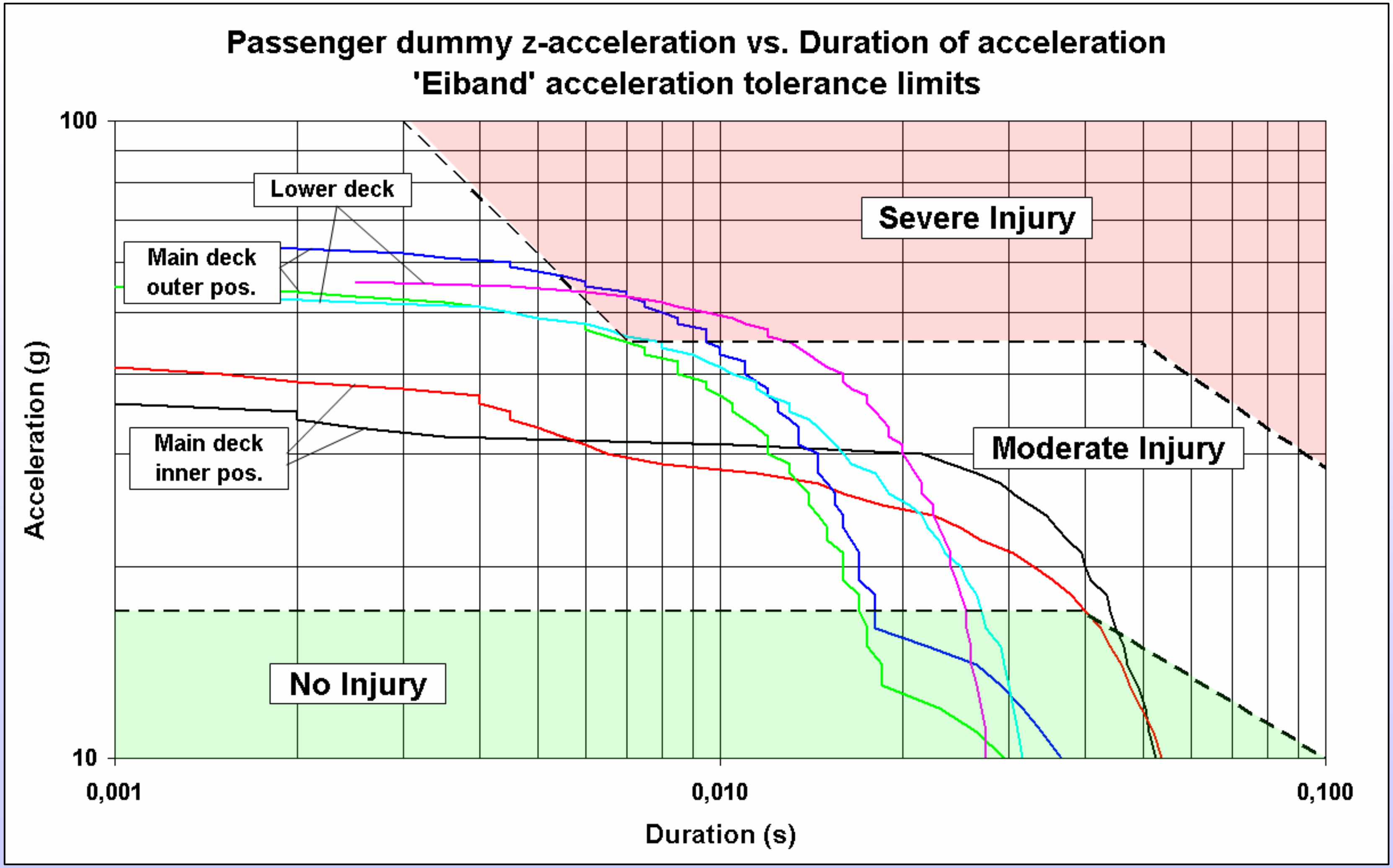
Limitations

- Simulated acceleration pulses have different shape than original Eiband test pulses
- a modified Eiband approach has to be used
- exact value for the probability of injuries can not be specified
- qualitative comparison of results

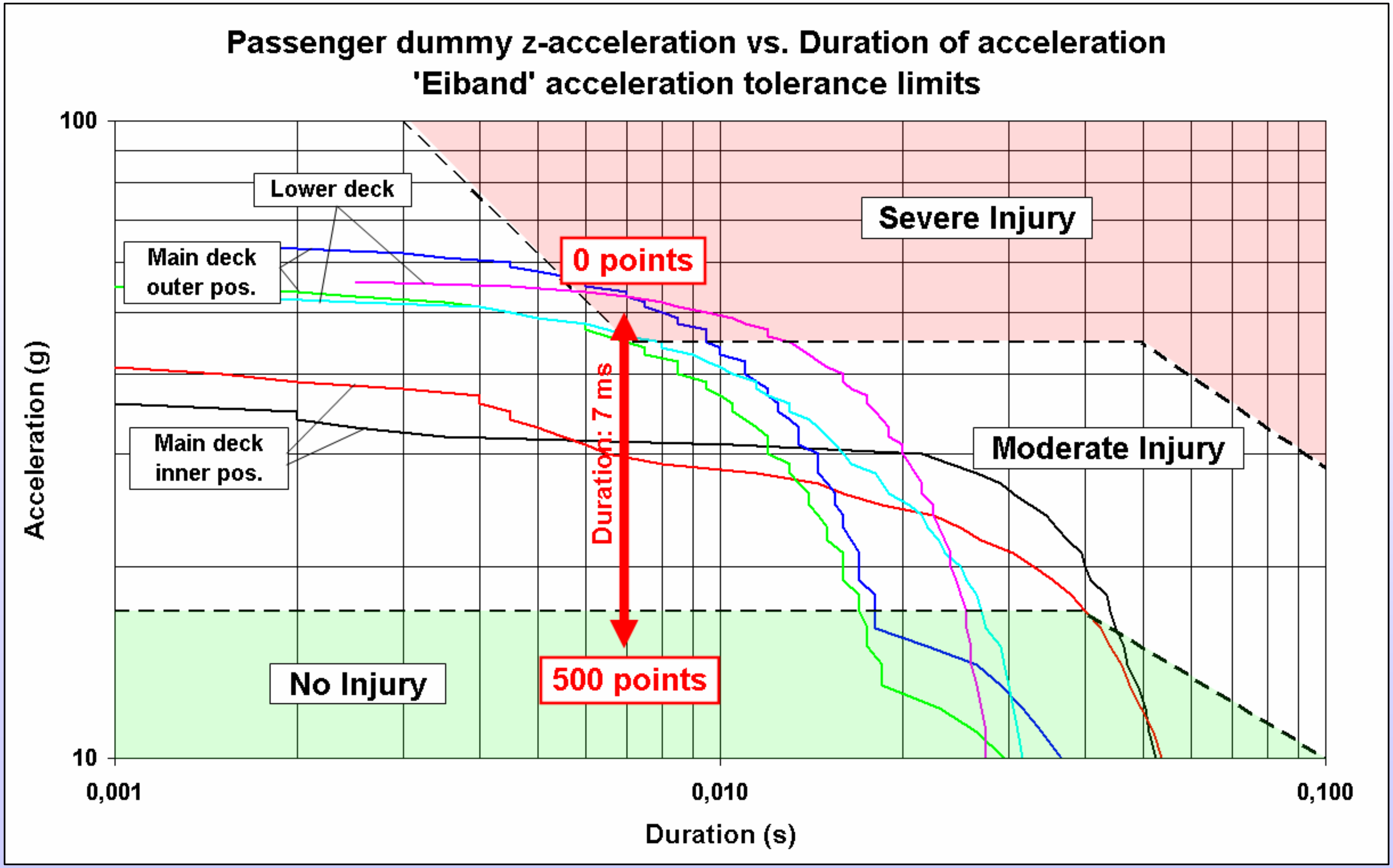
EIBAND evaluation of acceleration pulses



EIBAND evaluation of acceleration pulses

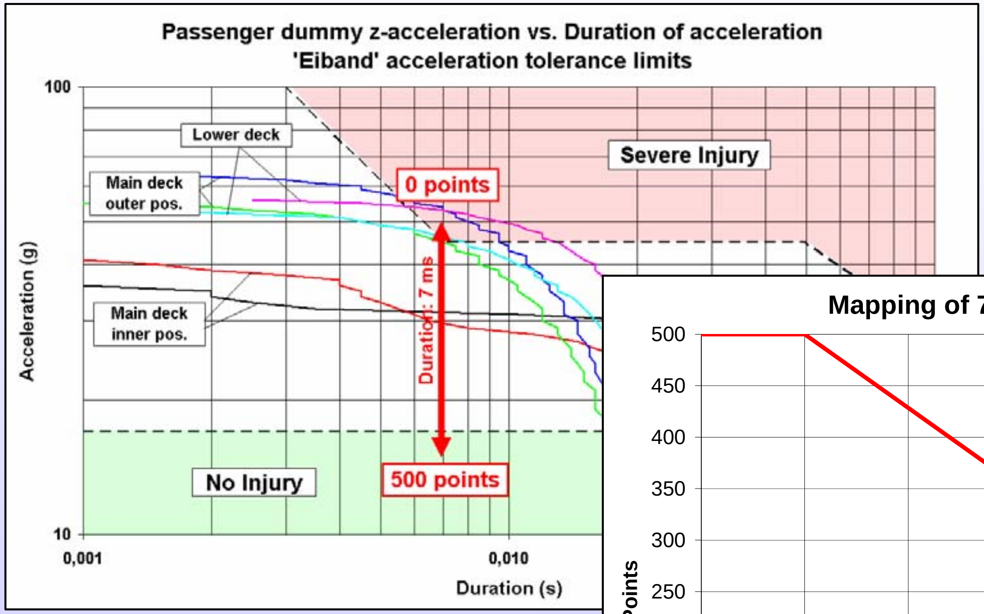


EIBAND evaluation of acceleration pulses

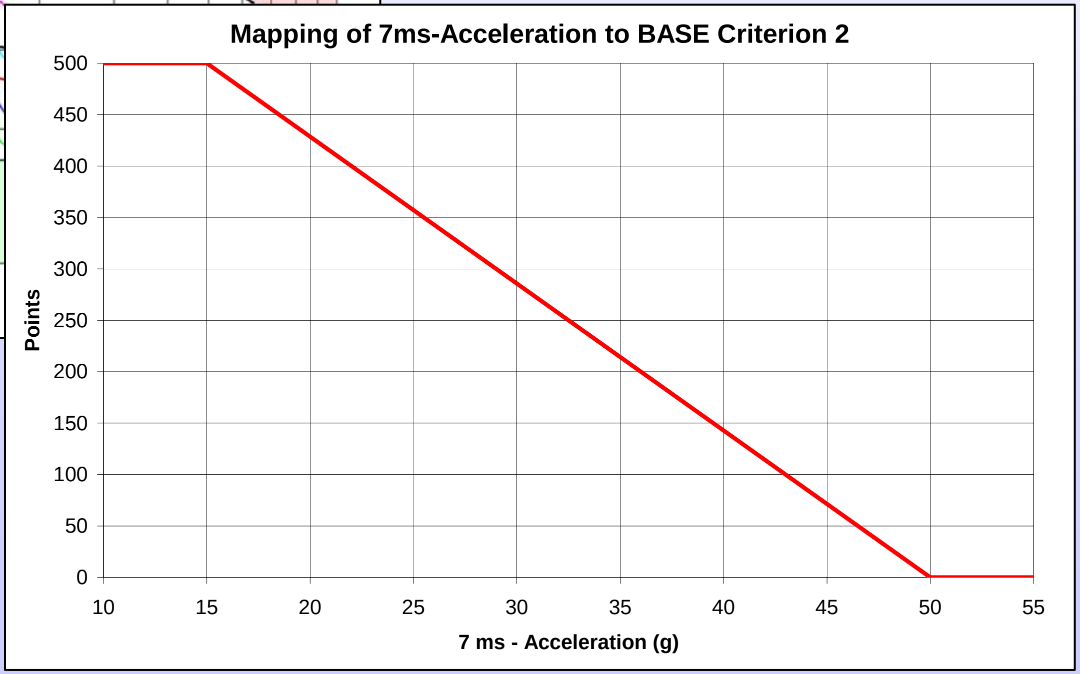


Assessment of Occupant Safety in different LDS Configurations

BASE – Criterion 'Acceleration' => max. 500 points (50%)

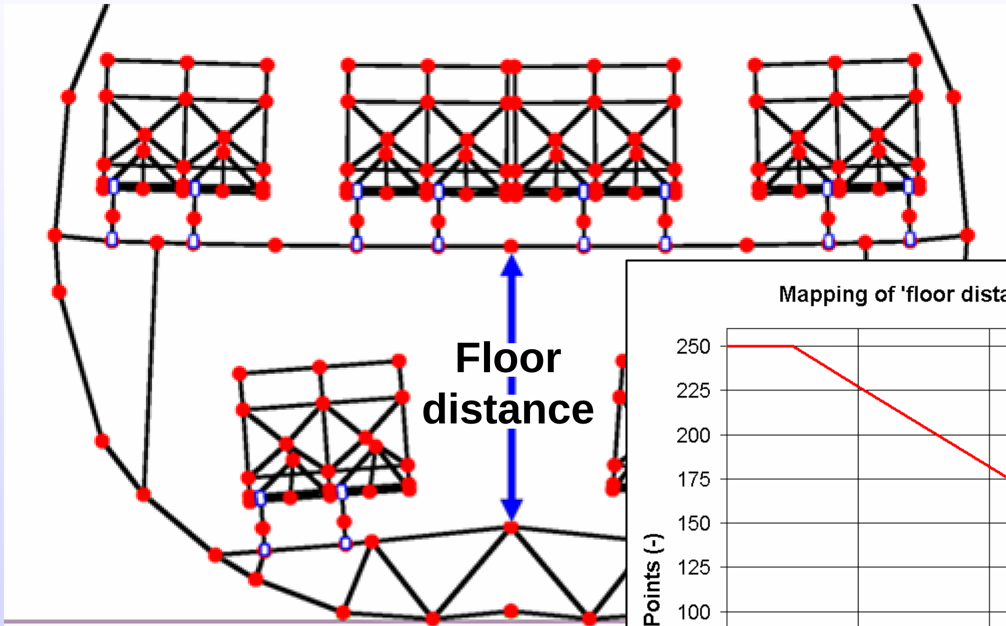


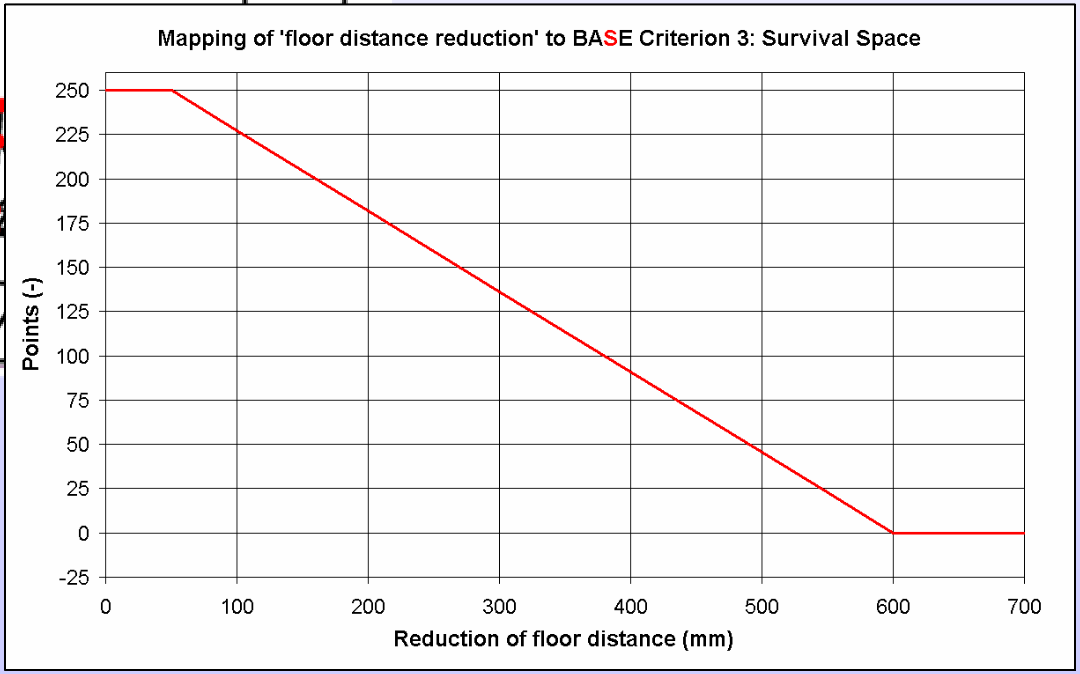
Mapping of 7ms-Acceleration to BASE Criteria points



Assessment of Occupant Safety in different LDS Configurations

BASE – Criterion 'Survival Space' => max. 250 points (25%)





Assessment of Occupant Safety in different LDS Configurations

BASE – Criterion 'Luggage Bin' => max. 150 points (15%)

Each seat position is judged according to the probability that luggage or bins can harm the occupant
(no overhead luggage bin = 150 points)

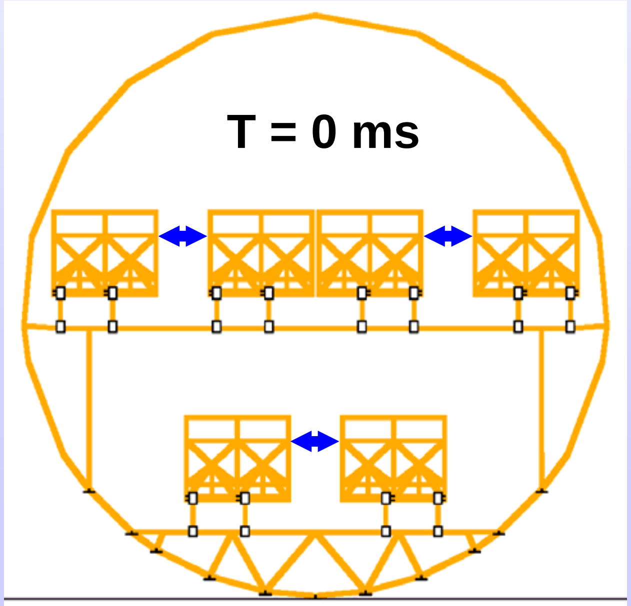
Source: FAA report no. DOT/FAA/AR-99/87

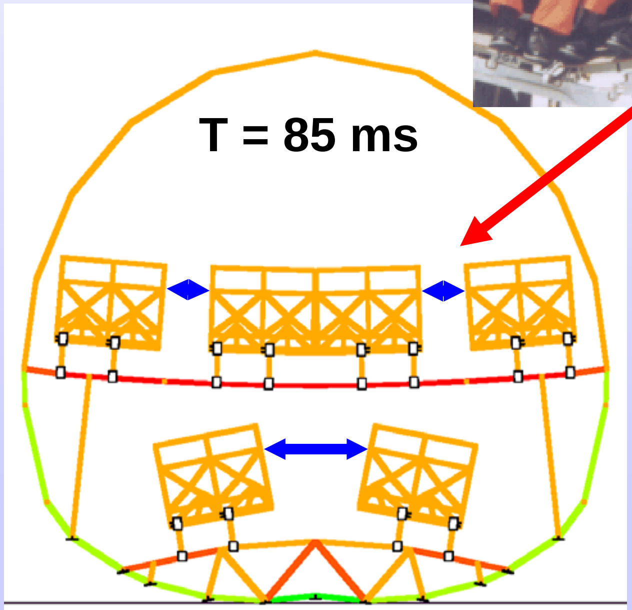
Source: AAIB (UK), Accident Report No: 4/90 (EW/C1095)

Assessment of Occupant Safety in different LDS Configurations

BASE – Criterion 'Escape Route' => max. 100 points (10%)

Each seat location is judged according to the size of the remaining aisle width and the position relative to the aisle
(aisle seat gets more points than window seat)





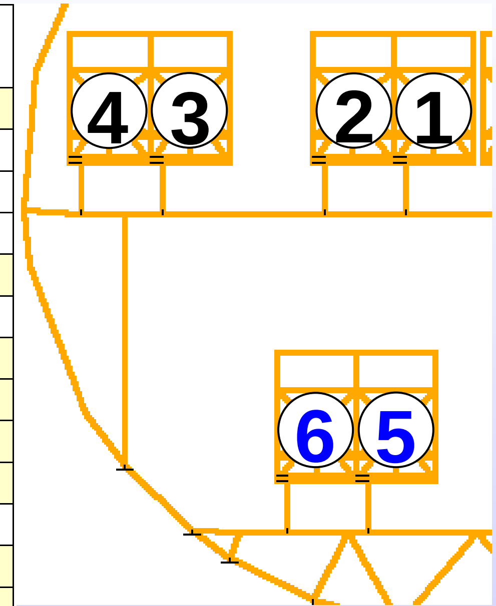
Main deck: aisle width is reduced

Lower deck: aisle width is increased

Assessment of Occupant Safety in different LDS Configurations

BASE – Criteria: Overall results

Con-figuration	Seat 1	Seat 2	Seat 3	Seat 4	Seat 5	Seat 6	Average	Min. value (out of 6)
148	787	767	659	597	**536**	545	648	**536**
133	677	767	667	604	**532**	631	646	**532**
140	711	777	671	601	**517**	596	646	**517**
152	753	724	590	521	**510**	520	603	**510**
151	810	830	751	691	**509**	566	693	**509**
143	726	787	664	594	**507**	587	644	**507**
145	621	651	549	**499**	613	589	587	**499**
128	799	830	736	723	**490**	587	694	**490**
45	600	626	519	**479**	566	531	553	**479**
48	781	751	641	586	501	**478**	623	**478**
149	727	669	543	**467**	533	499	573	**467**
142	780	827	823	757	**464**	592	**707**	**464**
139	779	823	793	754	**461**	619	705	**461**
33	667	756	629	543	**440**	556	598	**440**
49	721	657	516	443	449	**439**	537	**439**

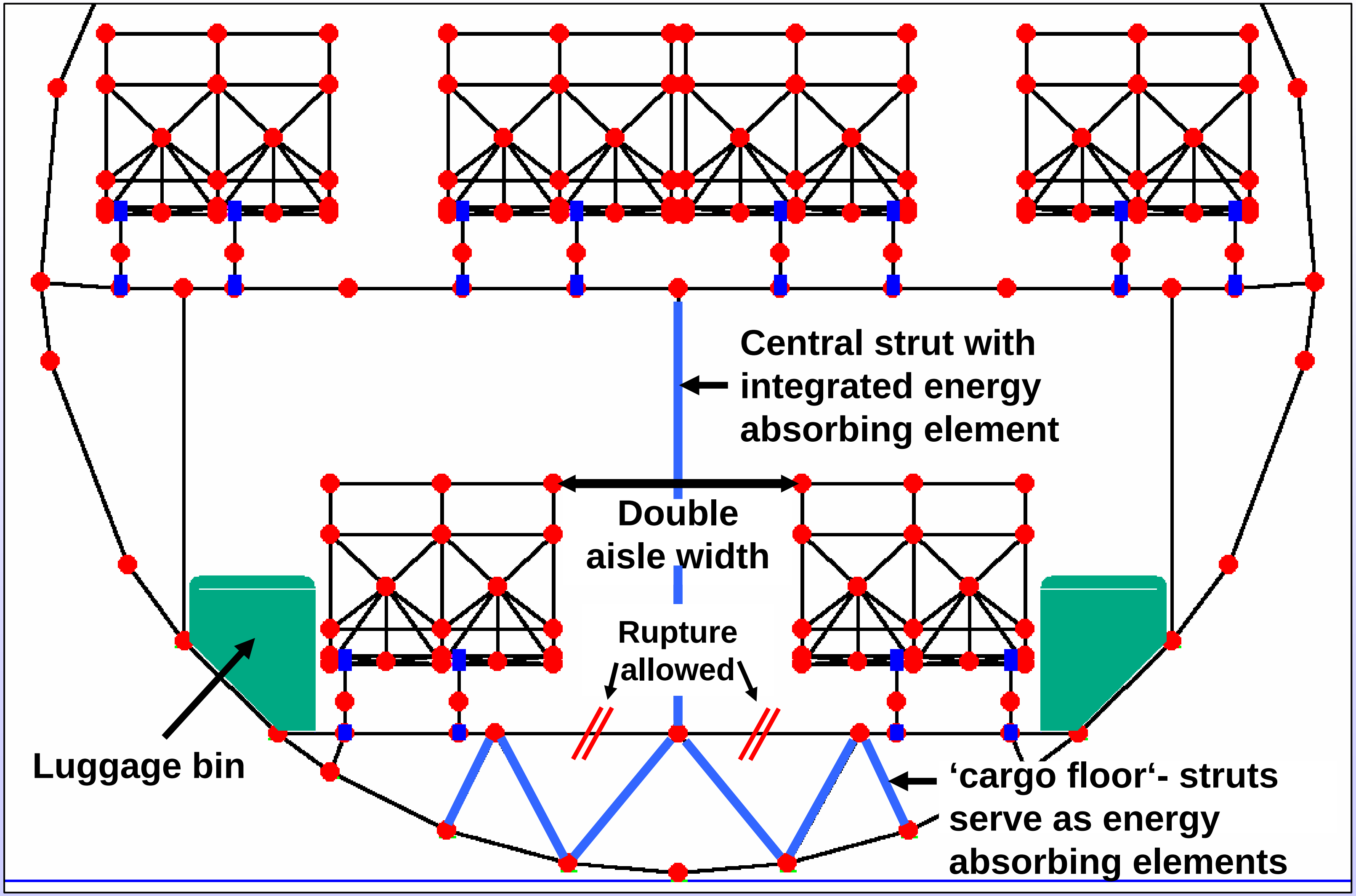


Best result for configuration 148

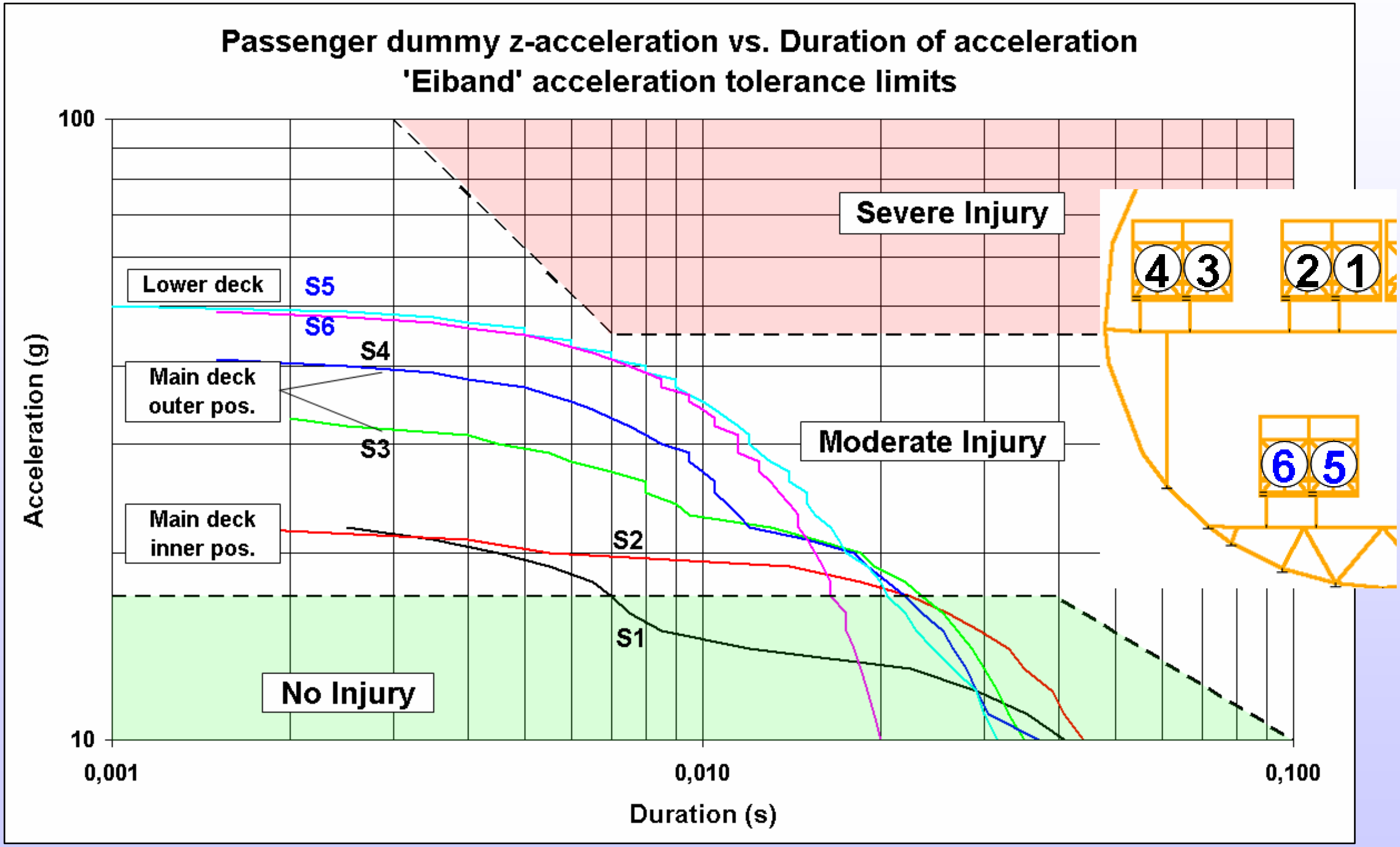
Occupant safety level reaches approximately 85% of the main deck level

(Basis of comparison: Seat 4 in original basic configuration)

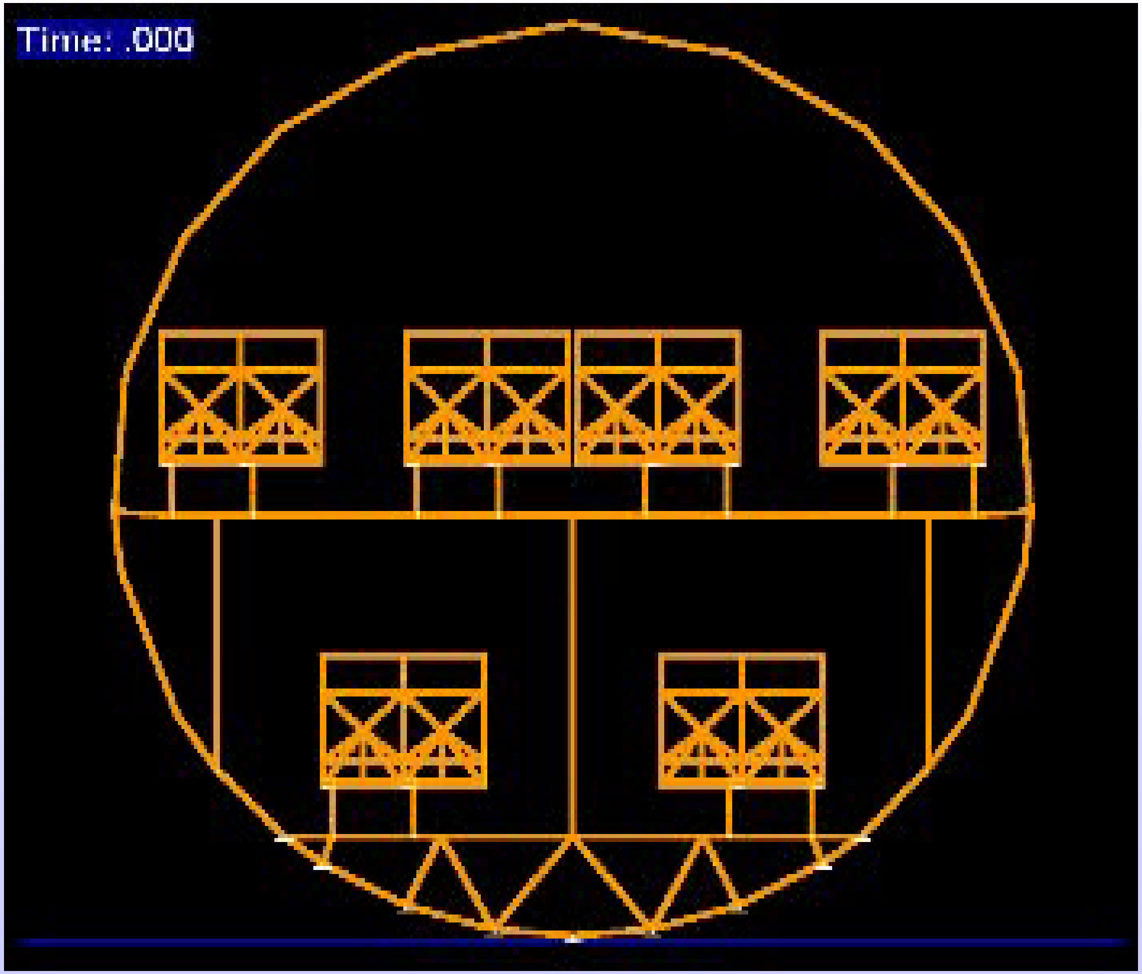
Proposed LDS Configuration (148)



EIBAND diagram for proposed LDS configuration



Animation of proposed LDS configuration

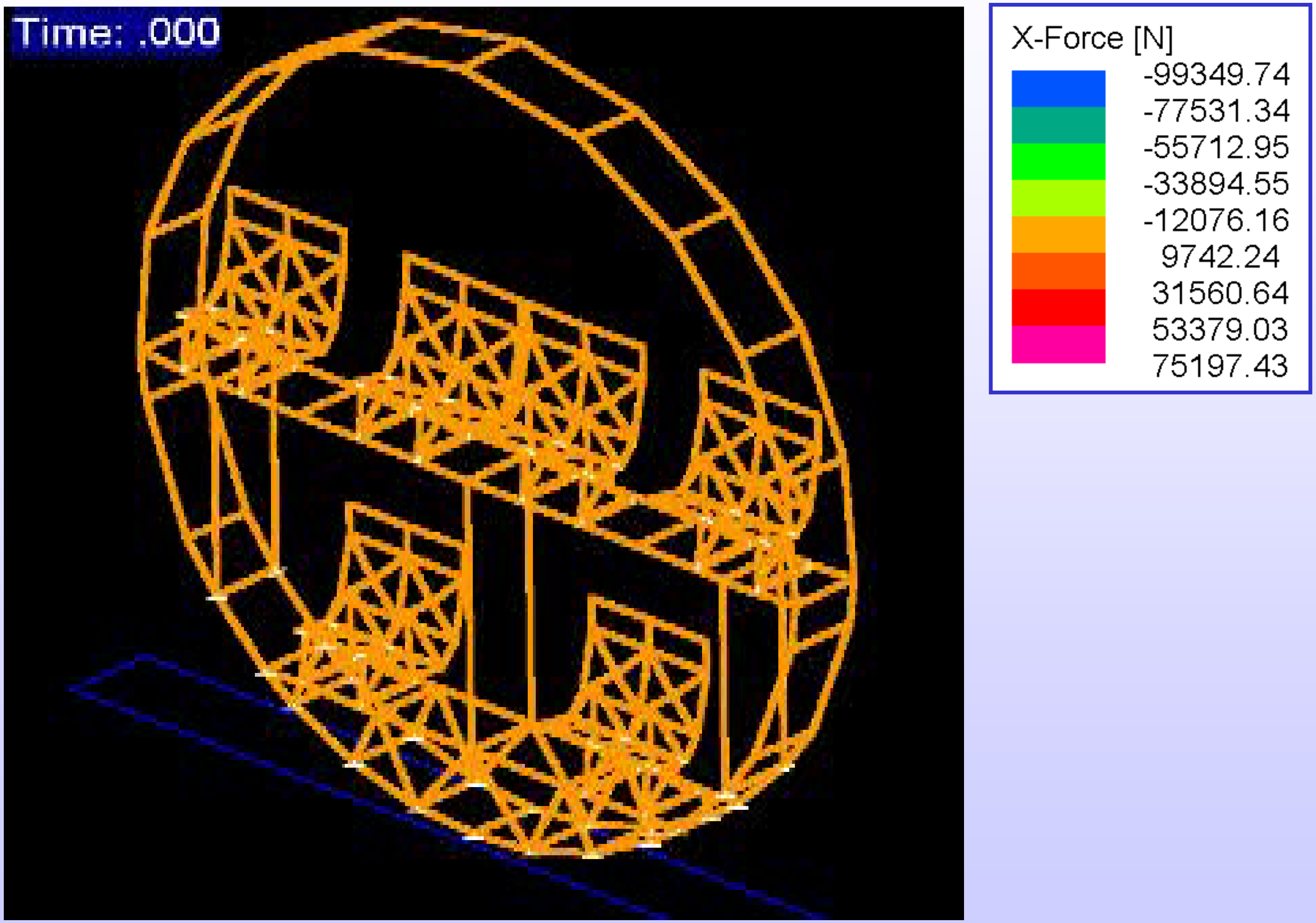


X-Force [N]
-99349.74
-77531.34
-55712.95
-33894.55
-12076.16
9742.24
31560.64
53379.03
75197.43

DLR_L148f_KAP.avi

***KAP* – KRASH Animation Program**

Animation of proposed LDS configuration



DLR_L148p_KAP.avi ***KAP*** **– KRASH Animation Program**

Guidelines for the realization of Lower Deck Seating – resulting from the LDS parametric study

- **In order to secure the survival space for the occupants in the lower deck area, additional struts should be used (between lower and main deck).**
- **These additional struts between the floors must not be 'stiff' like the standard passenger floor struts as such a design would increase the accelerations on both floors.**
- **These extra struts must include energy absorbing elements (a reduction of the distance between the two floors has to be allowed).**
- **The 'cargo floor'- struts should also be designed as energy absorbing elements.**
- **Moving the LD seats further outwards (increasing the aisle width) reduces the accelerations on the LD passengers and provides a better escape route (has also advantages in the 'normal' aircraft operation).**
- **Luggage bins should not be attached to the main deck floor cross beams but placed in the outer area of the lower deck (attached to the LD floor).**

Conclusions

- Different DRI-KRASH models of a wide-body fuselage section, the seats and the occupants were set up in a parametric way.
- The BASE Criteria were established for the comparison of occupant safety in the different Lower Deck Seating (LDS) configurations.
- Crash simulation calculations with numerous configurations were carried out in an extensive parametric study and in each case evaluated according to the presented BASE criteria.
- DRI-KRASH proved to be an excellent tool for doing a wide range of parametric studies in a relatively short time.
- A configuration was chosen where the occupant safety level reaches approximately 85% of the main deck level.
- Further improvements are required and seem to be feasible.
- The here developed LDS design rules could contribute to a possible future use of the cargo compartment as additional passenger cabin.

Thank you for your attention!

www.dlr.de

www.dri-krash.com

www.mlsoftware.de