GOVERNMENTATTIC.ORG
Videre licet
- 2007 -

governmentattic.org

"Rummaging in the government's attic"

Description of document:	National Aeronautics and Space Administration (NASA) Subject: Orion Landing System Lessons Learned 2013
Requested date:	25-October-2025
Release date:	12-January-2026
Posted date:	26-January-2026
Source of document:	FOIA request NASA Headquarters 300 E Street, SW Room 5Q16 Washington, DC 20546 Fax: (202) 358-4332 Email: hq-foia@nasa.gov [FOIA.gov](https://www.foia.gov)

The governmentattic.org web site ("the site") is a First Amendment free speech web site and is noncommercial and free to the public. The site and materials made available on the site, such as this file, are for reference only. The governmentattic.org web site and its principals have made every effort to make this information as complete and as accurate as possible, however, there may be mistakes and omissions, both typographical and in content. The governmentattic.org web site and its principals shall have neither liability nor responsibility to any person or entity with respect to any loss or damage caused, or alleged to have been caused, directly or indirectly, by the information provided on the governmentattic.org web site or in this file. The public records published on the site were obtained from government agencies using proper legal channels. Each document is identified as to the source. Any concerns about the contents of the site should be directed to the agency originating the document in question. GovernmentAttic.org is not responsible for the contents of documents published on the website.

-- Web site design Copyright 2007 governmentattic.org --

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

January 12, 2026

Reply to attn. of: Office of Communications
History and Information Services Division

Re: FOIA Tracking Number **26-00032-F-HQ**

This responds to your Freedom of Information Act (FOIA) request to the National Aeronautics and Space Administration (NASA), dated October 25, 2025, and received in this office on October 27, 2025. You seek:

> *A copy of the SLIDES for each of these NESC Academy (NASA Engineering and Safety Center) videos. The SLIDES are locked on the website so they cannot be viewed by the public.*
> *A copy of the SLIDES and VIDEOs for parts 2 and 3 listed in item 12 below.*
>
> *1) Lunar Landing*
> *https://nescacademy.nasa.gov/video/427d8334fa41482797cae5cddf7d71a41d*
>
> *2 and 3) Selected Apollo & Shuttle Lessons Learned ({Parts 1 and Part 2)*
> *https://nescacademy.nasa.gov/video/9edb3c4de48e46d7b66f2a91ace96a171d*
> *https://nescacademy.nasa.gov/video/27784b7aa2ce4c628d77143c86232d621d*
>
> *(4, 5, 6 and 7) Failure Recovery (Parts 1, 2, 3 and 4)*
> *https://nescacademy.nasa.gov/video/9efbd739aeae4da6b8a80b7370ccff051d*
> *https://nescacademy.nasa.gov/video/4e202def3eb943c99e4ba2744676392c1d*
> *https://nescacademy.nasa.gov/video/9965475c1f2649c4a56aad45cbc553ab1d*
> *https://nescacademy.nasa.gov/video/44323a56200341a198d3911002f0eb211d*
>
> *8, 9 and 10) Lessons Learned from Fifty Years of Observing Hardware and Human Behavior, Parts 1, 2 and 3*
> *https://nescacademy.nasa.gov/video/c81ccbfd7909415ea72070bbf1c8e38f1d*
> *https://nescacademy.nasa.gov/video/e84a2cc167244d14ac623358f2e9526a1d*
> *https://nescacademy.nasa.gov/video/79e6fd6fc7544b0ba7525f31ed2d866e1d*
>
> *11) Using TRIZ for Engineering Innovation*

https://nescacademy.nasa.gov/video/a42a19ce39a14cd49dfb669e774812b71d

12) Orion Landing Attenuation: slides for Part 1, Part 2, and Part 3. Copy of the video presentation for Part 2 and Part 3 https://nescacademy.nasa.gov/video/806485bdd20041cda2445409cf5737e21d

In response to your request we conducted a search of NASA's Langley Research Center, Engineering and Safety Center (NESC) using the information from your request. NASA's search began on November 18, 2025 and any records created after this date are not included with this response. That/Those search(es) identified the enclosed records that are responsive to your request. We determined that all **533** pages and 2 videos (Orion Part 2 - 55 minutes, 42 seconds; Orion Part 3 - 47 minutes, 52 seconds) are appropriate for release without excision and copies are enclosed.

Appeal

If you believe this to be an adverse determination, you have the right to appeal my action on your request. Your appeal must be received within 90 days of the date of this response. Please send your appeal to:

Administrator
NASA Headquarters
Executive Secretariat
ATTN: FOIA Appeals
MS 9R17
300 E Street S.W.
Washington, DC 2054

Both the envelope and letter of appeal should be clearly marked, "Appeal under the Freedom of Information Act." You must also include a copy of your initial request, the adverse determination, and any other correspondence with the FOIA office. In order to expedite the appellate process and ensure full consideration of your appeal, your appeal should contain a brief statement of the reasons you believe this initial determination should be reversed. Additional information on submitting an appeal is set forth in the NASA FOIA regulations at 14 C.F.R. § 1206.700.

Assistance and Dispute Resolution Services

If you have any questions, please feel free to contact me at derek.m.moore@nasa.gov. For further assistance and to discuss any aspect of your request you may also contact:

Stephanie Fox
FOIA Public Liaison
Freedom of Information Act Office
NASA Headquarters
300 E Street, S.W., 5P32
Washington D.C. 20546
Phone: 202-358-1553
Email: Stephanie.K.Fox@nasa.gov

Additionally, you may contact the Office of Government Information Services (OGIS) at the National Archives and Records Administration to inquire about the FOIA mediation services it offers. The contact information for OGIS is as follows: Office of Government Information Services, National Archives and Records Administration, 8601 Adelphi Road-OGIS, College Park, Maryland 20740-6001, e-mail at ogis@nara.gov; telephone at 202-741-5770; toll free at 1-877-684-6448; or facsimile at 202-741-5769.

Important: Please note that contacting any agency official including myself, NASA's FOIA Public Liaison, and/or OGIS is not an alternative to filing an administrative appeal and does not stop the 90 day appeal clock.

Sincerely,

Derek Moore

Derek Moore
Government Information Specialist

Innovative Engineering
Lesson 7: Orion Landing Attenuation

Background
Ed Fasanella

Themes Addressed




Lesson 7: Orion Landing Attenuation Background

Dr. Ed Fasanella

Overview of Parachute Landing Systems with Applications for ORION

Apollo water & soil landing test & analysis

Parachute Systems

- Much lighter than “wing & wheels” landing systems
- Practical weight limit of 40,000-lb payload
- Multiple chutes needed for reliability
- Terminal velocity typically 25–40 ft/s
- Operational manned systems include Mercury, Gemini, Apollo, Soyuz, Cirrus, F-111 escape module

Apollo Program Testing

- 200+ impact tests performed
  - Most were subscale tests & full-scale boilerplate tests
- At least 15 tests were performed on flight-like test articles
  - BP-28 was hybrid boilerplate with flight-like aft bulkhead, barrel section & heat shield used for many drops; was constructed so damaged sections could be replaced
  - 6 flight structures (mix of Block I & Block II) were used for water & land impact tests
- Water & land landing tests were performed at North American Aviation's gantry in Downey, CA
- Additional testing was performed at LaRC gantry & at test rig at MSC (JSC)

Soyuz Program Testing

- Numerous drop tests as well as airborne tests on boilerplate & flight articles (TM & TMA configurations)
- Evaluated primary structure & measured shock pulses at crew seat for various landing conditions (30+ tests on boilerplate articles, 7 flight article tests)

Apollo Landing Experience

- Apollo intended to land on land with retrorockets
- Wanted to reuse capsules if possible
- Instead, tight schedule required water landings
- Orion is larger than Apollo, but Apollo experience is quite useful for designing Orion landing systems

North American Aviation Impact Facility

Apollo Land Impact Testing at Johnson Space Center

Operational Airbag Landing Systems

- Mars Exploration Rover
- F-111 escape module—relatively high injury rate
- Helicopter airbag systems (in development)

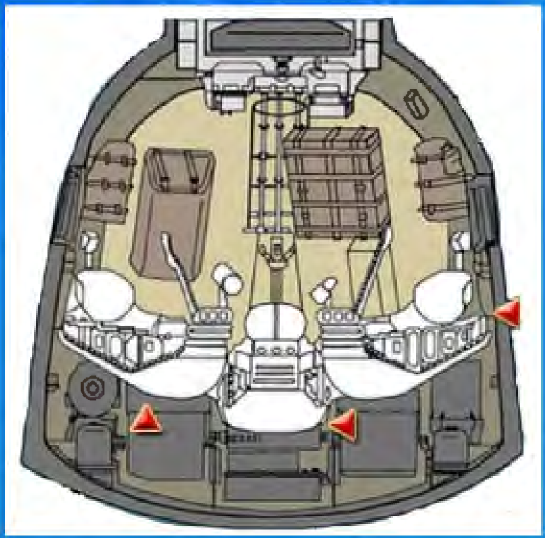
Raphael (Israel); Boeing UAV Helicopter, skid-mounted airbags

F-111 capsule drop tests NASA Langley 1980s–90s

Mars Exploration Rover airbags: vectran bags strapped together

Operational Retrorocket Landing Systems

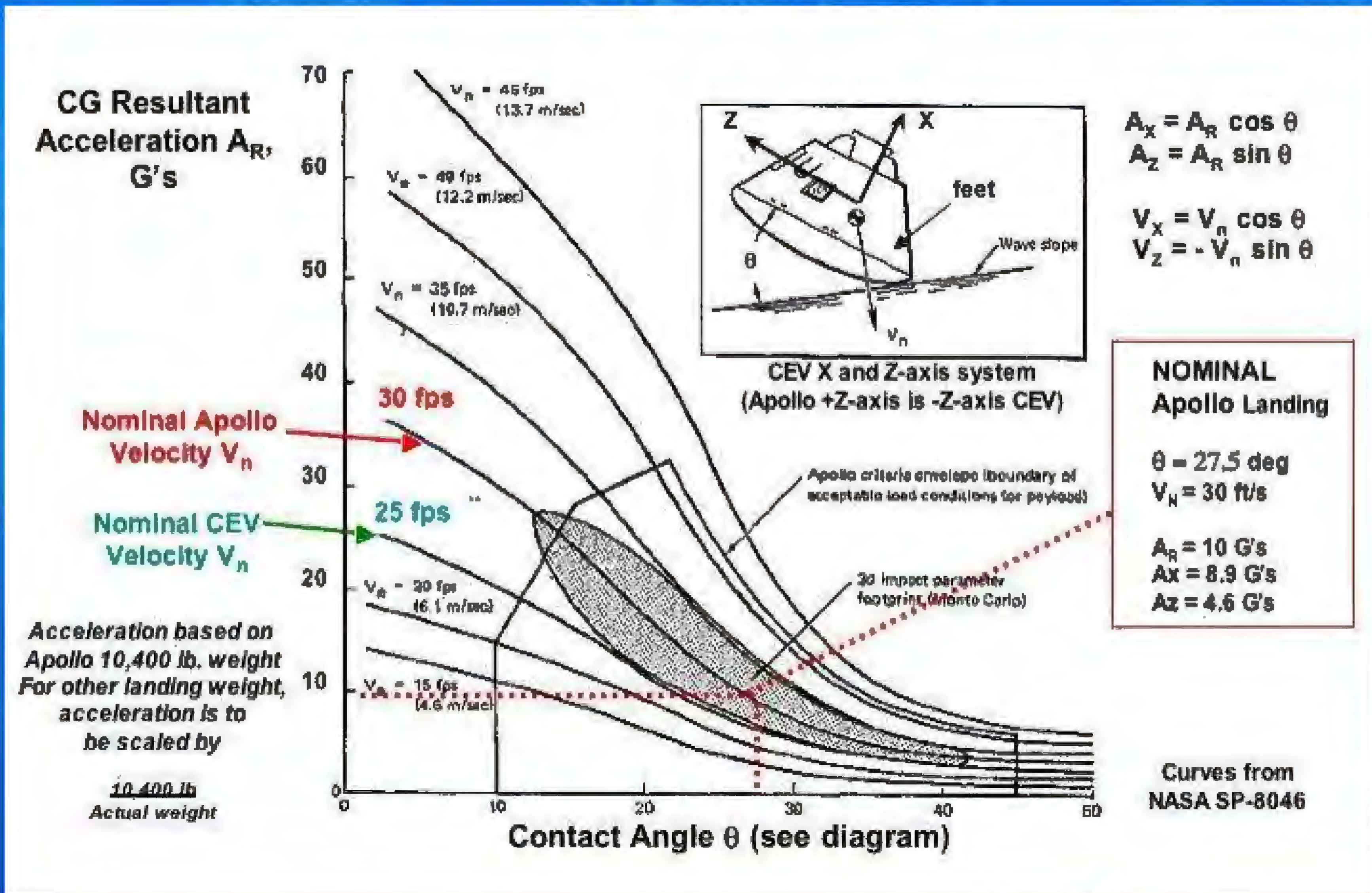
- Russian Soyuz & Chinese Shenzhou
- Single parachute terminal velocity ~ 25 ft/s
- Backup parachute terminal velocity ~ 30 ft/s
- 3 stroking seats with conforming liners
- Heatshield dropped, Cesium 137 altimeter
- 4–6 retrorockets fired
  ~ 3 ft above ground
- Velocity & acceleration reduced to single digits



Soyuz TMA capsule

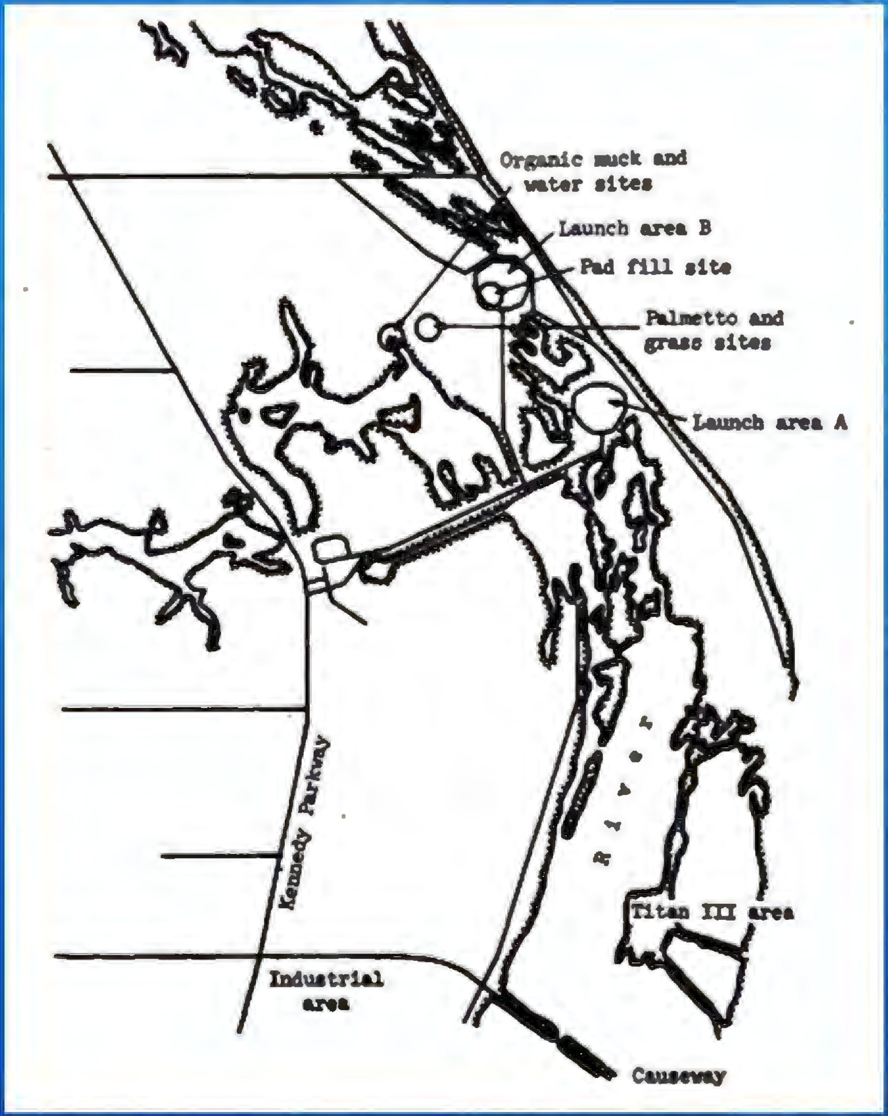
Confluence-mounted retrorocket cargo drops

Summary of Apollo Water Impact Data



Apollo Land Impact Test Sites at KSC

Apollo concerned about pad abort with land landing

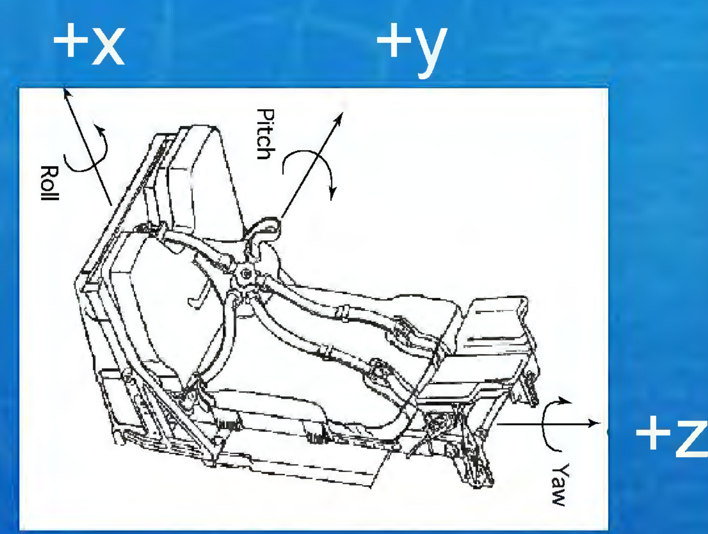


Surface type *	Percent coverage
Palmetto	**26**
Water	**24**
Grass	**18**
Organic muck	**13**
Fill material	**12**
Beach & sand	**7**

* Soil & vegetation study within 2-mile radius of Pads 39A & 39B

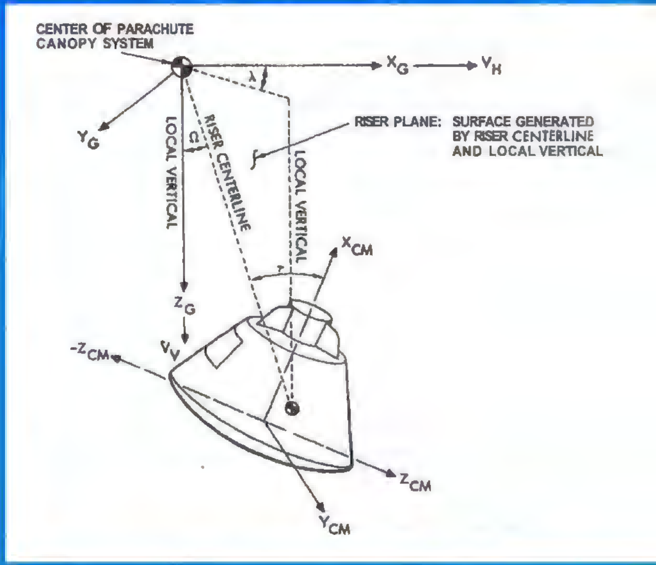
Human Tolerance to Acceleration

- Apollo boilerplate tests at vertical 31–41 ft/s, horizontal ~37 ft/s (J. McCullough)
- Test data from Apollo boilerplate tests at Kennedy showed duration of CG acceleration pulse for Z-direction of 0.02–0.1+ s depending on terrain (hard, mushy, shallow water, palmetto, etc.)
- Apollo capsule Z-accelerations for 27.5° pitch down cases were typically in very high range (chance of spinal injury 10–50+ %)
  - Z-acceleration in seat reference frame was due to combination of pitch & horizontal velocity
- X-acceleration (eyeballs in) was generally tolerable



Apollo Pad Abort Land Impact Test Data

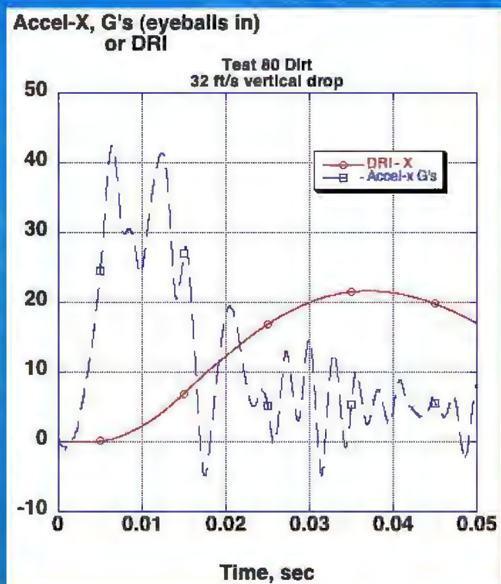
- Vertical velocities all higher than Orion's nominal 25 ft/s
- Shallow water accelerations are low
- Maximum X-acceleration of 40g (marginal)
- Maximum Z-acceleration of 28g (likely injurious)
- Stroking pallet would mitigate impacts



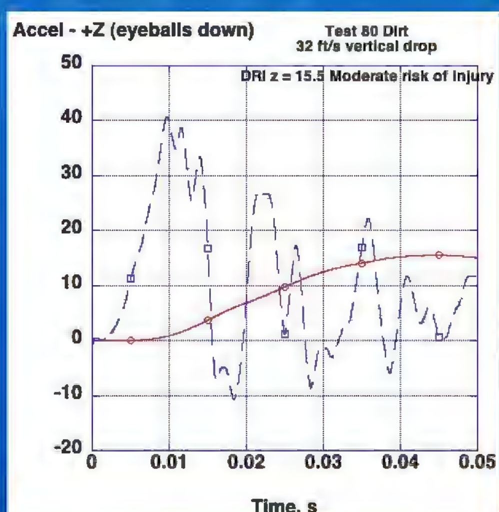
Test	Surface	Roll, deg	Pitch, deg	Vertical Vel, fps	Horizontal Vel, fps	Peak CG +X-acc G	Peak CG -Z-acc G
1	Grass	0	-27.5	39.1	36.5	19	22
2	Grass	180	-27.5	39.8	37.4	26	12
3	Palmetto	0	-27.5	37.2	36.4	25	**28**
4	Palmetto	180	-27.5	37.2	38.8	**40***	8
5	Organic muck	0	-27.5	41.7	37.9	14	5
6	Organic muck	180	-27.5	41.3	37.1	23	20
7	Shallow water	0	-27.5	39.4	36.1	8	5
8	Shallow water	180	-27.5	39.9	38.2	18	6

Comparison of Full-Scale Apollo Water & Soil Impact Tests

Test 80 Soil Impact Test



DRI x = 22 very low chance Injury

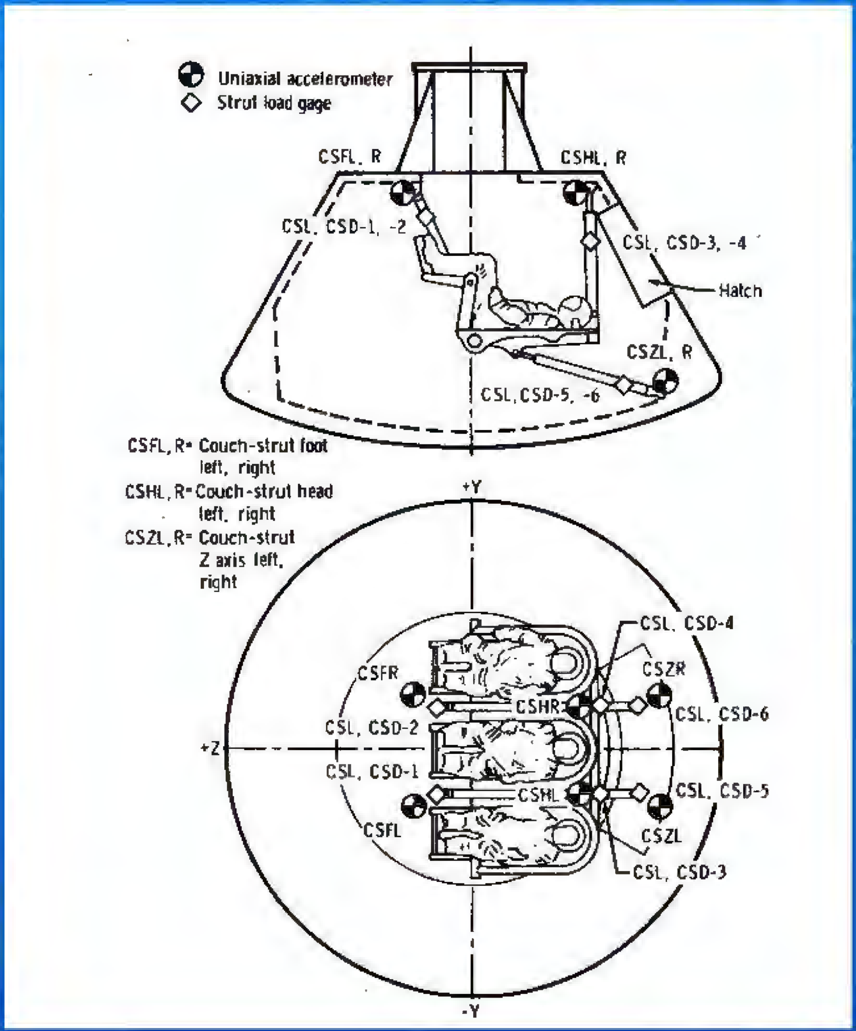


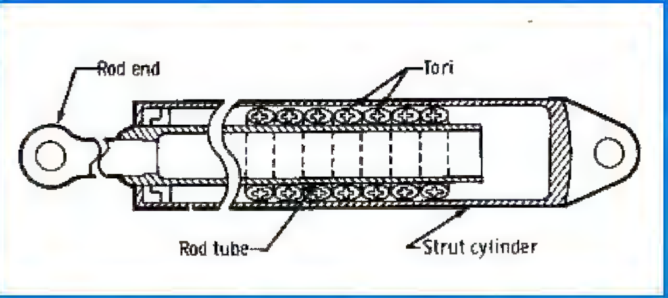
DRI z = 15.5 Low/moderate chance Injury

	Velocity		Water Impact			Soil Impact		
Pitch (down)	Hori z	Vert	Test	Max Acc X	Max Acc Z	Test	Max Acc X	Max Acc Z
-27.5	0	32	*	8	3	80**	40	40
-27.5	0	38	*	17	9	81**	50	50
-27.5	25	32	*	9	3	16**	43	45
-27.5	45	32	*	10	3	31**	30	50
~ -10	0	~23	90***	13.9	3.5	*	29	14

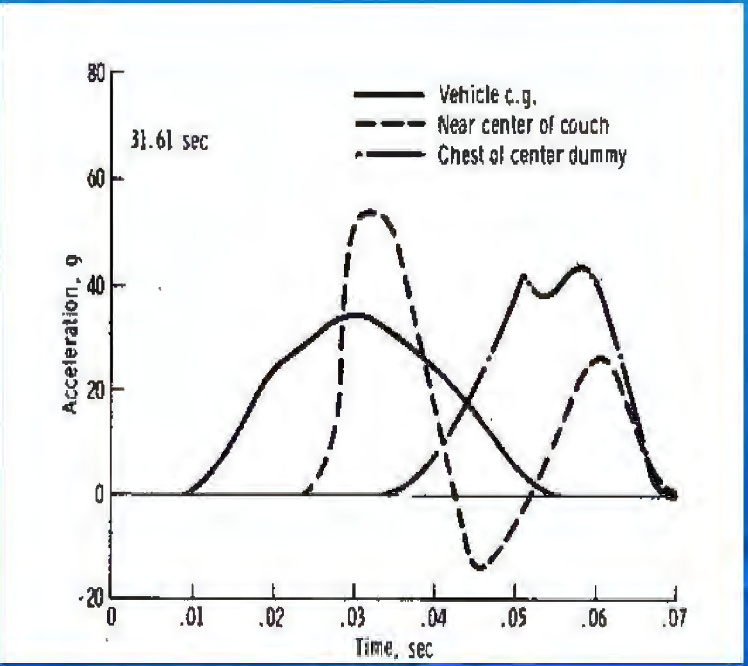
DRIz	Injury Rate	Brinkley DR level
13.1	<0.2 %	very low
15.2	<0.5 %	low
18	~5 %	moderate
22.4	30-50%	high

Apollo Stroking Pallet for Acceleration Attenuation





One style Apollo Strut



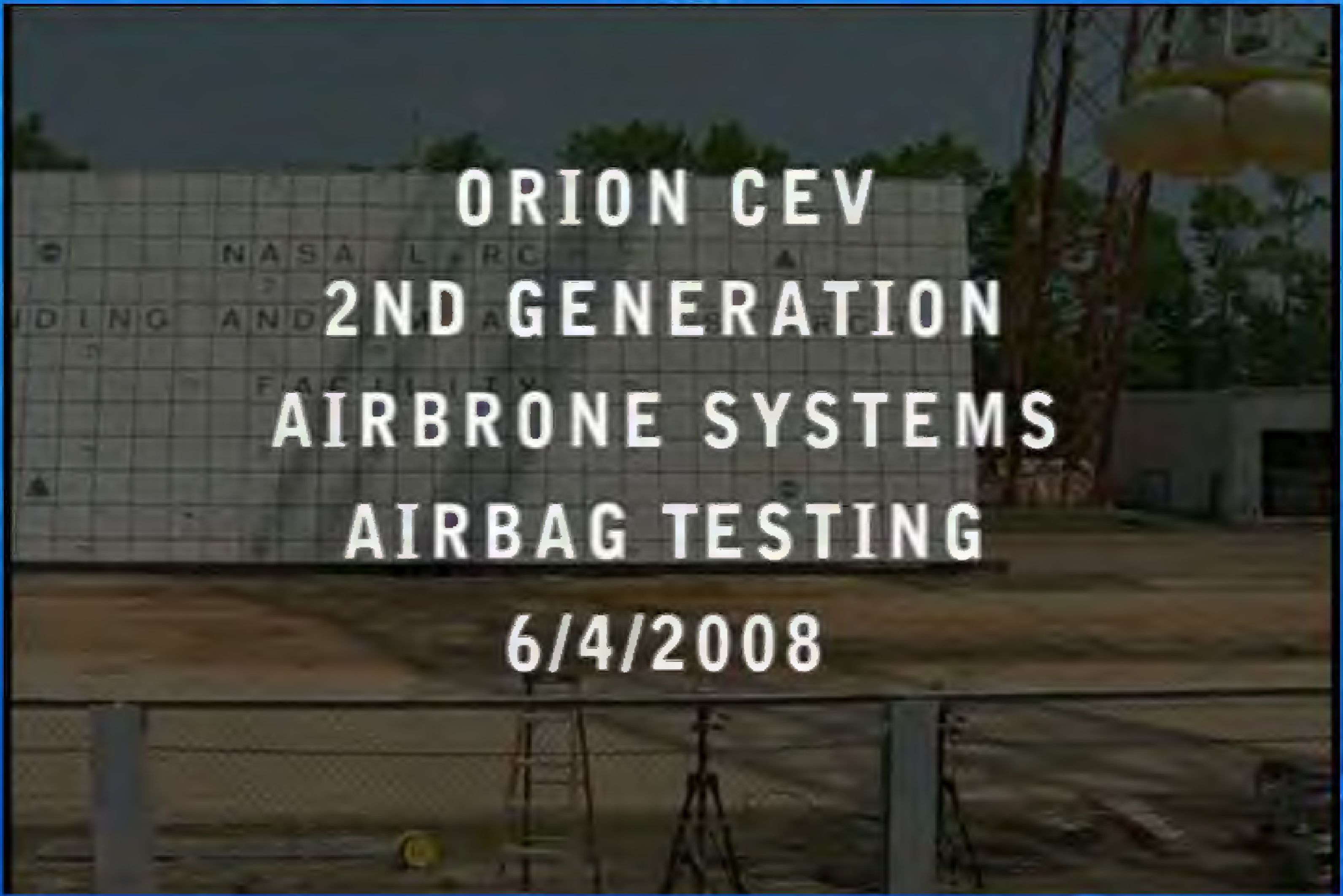
Soil impact test data

PM SG-33, 34

Concepts Rated for Land Landing Team at Langley

- Deployable landing legs after heat shield deployed
- Retrorockets after heat shield deployed or through blowout plugs in heatshield
- Deployable energy absorber after heat shield deployed
- Airbags after heat shield deployed
- Airbags deployed from side of capsule, heat shield retained
- Retrorockets initially rated higher than airbags, but when reusability was considered, airbags won out

Orion Land Landing Test/Analysis at LaRC



Summary

- Designing contingency land landing (CLL) system for Orion continues to be challenge
- Priorities include low weight & “no” injury to crew
- Current Orion landing criteria requires a low Brinkley number for combined loading directions (low risk <1 using model)
- Airbag systems have shown promise, but have reliability & weight issues
- Much data applicable to Orion have been gained by examining past systems like Apollo, F-111 escape module & other parachute landing systems
- Finite element simulations will play large role in optimizing landing system for multi-terrain

Lesson 7: Orion Landing Attenuation

Design Challenge

Joe Pellicciotti

Themes Addressed

Lesson 7: Orion Landing Attenuation Design Challenge

Joe Pellicciotti

Discussion Outline

- Problem overview
  - Goals & objective
  - Orion cockpit configuration
- Design constraints
- Design interface description
- Analysis tools used by NASA team
  - Design
    - Computer aided design (CAD)
    - Engineering tests
  - Analyses
    - Excel
    - NASTRAN
    - ADAMS
    - LS-Dyna
    - Brinkley model
- Problem summary

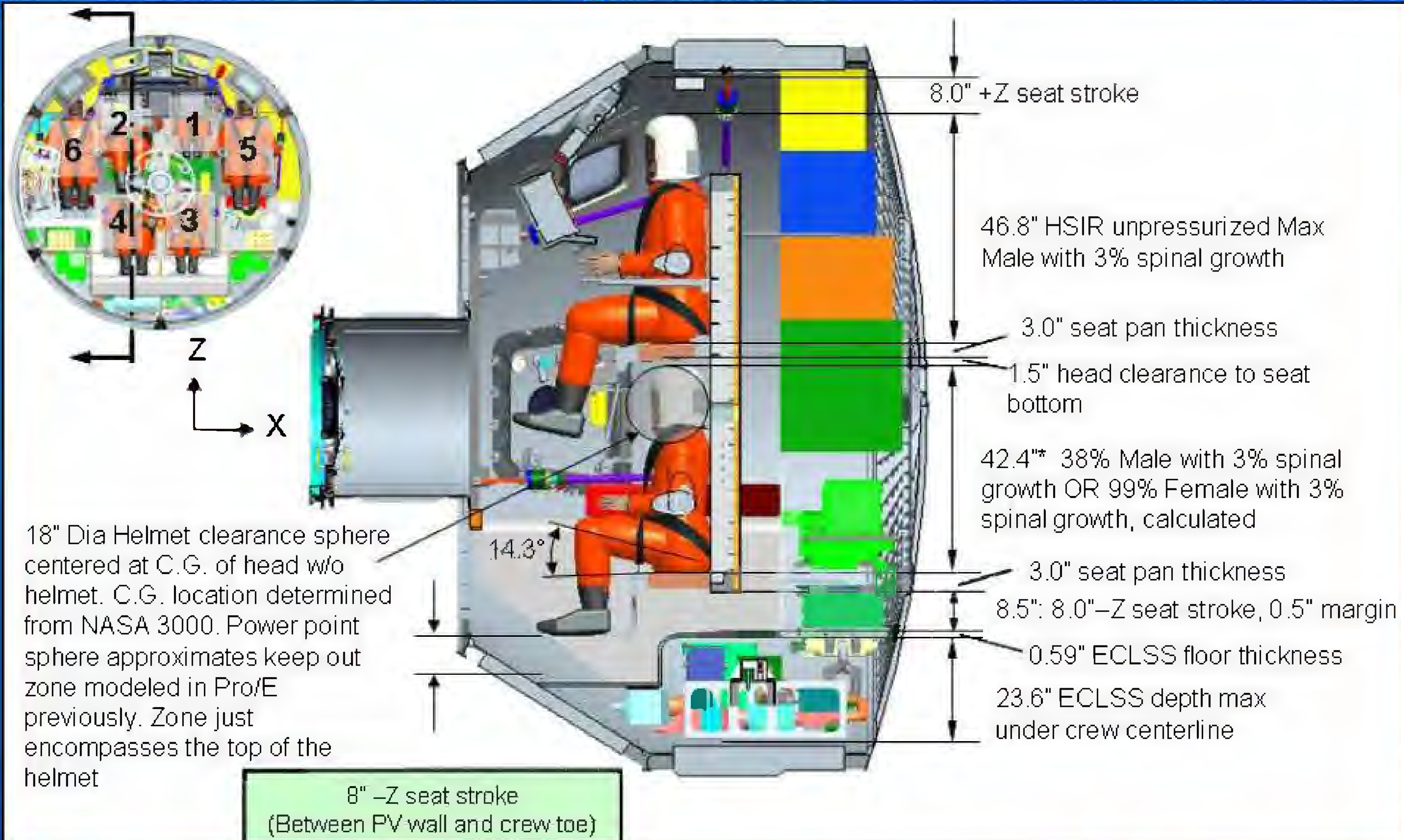
Design Problem Overview

"The Challenge"—Apollo Video

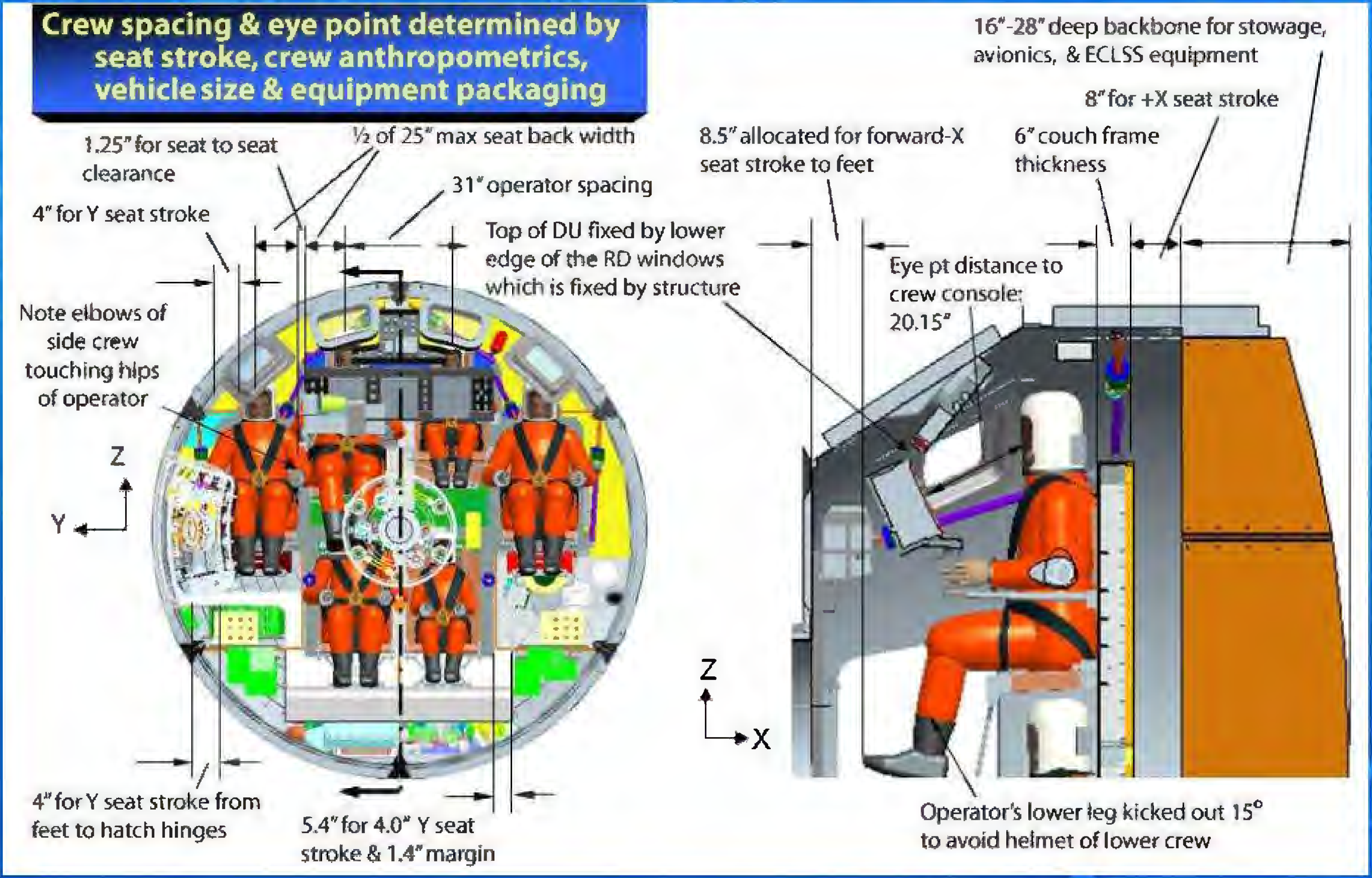
Goals & Objective

- System goal:
  - Develop best occupant protection system possible for Orion that maximizes crew safety during ascent, ascent aborts (if required), landing (water nominal with land landing contingency) & post-landing recovery
- Design team objective:
  - Independently develop alternate crew seat/attenuation scheme to increase robustness & minimize risk of crew injuries. Activities include assessment of current & existing designs & investigation of alternative seat attenuation systems

LM 606C Baseline Design Z Spacing

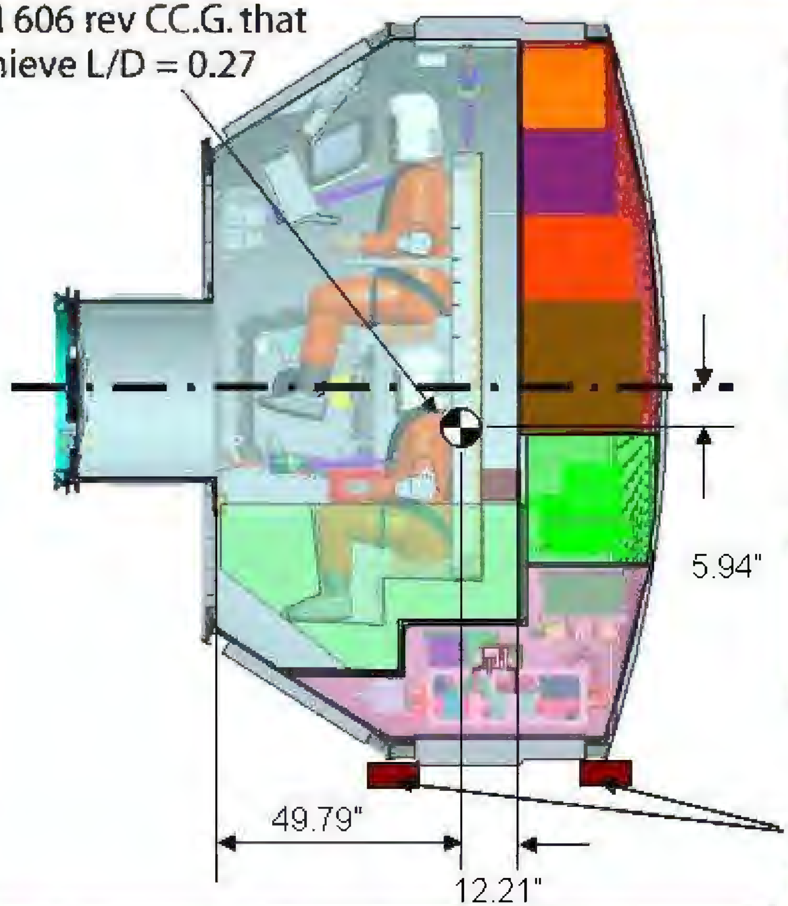


LM 606C Cockpit Spacing X & Y Limitations



606C CG Location & Equipment Packaging Sensitivity

CM 606 rev C C.G. that achieve L/D = 0.27



Internal lunar mass summary chart

Bay	Weight [lbs] w/WGA	Volume [ft³]	*Density [lb/ft³]*
ECLSS	1228	54	22.7
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Crew Habitat	2065	398	5.2

Values include wiring, tubing, lighting, 2nd structure, & lunar rocks. Crew console located in Crew Habitat volume for this calculation

To meet C.G. requirements while not sacrificing NHV, dense volumes need to be located low in CM interior

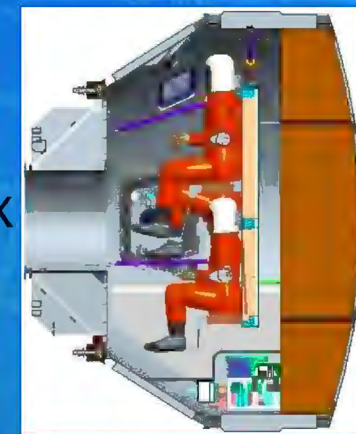
Projected ballast locations
Lunar ballast to achieve L/D 0.27: 330 lbs
ISS ballast to achieve L/D 0.27: 550 lbs

L/D without ballast is 0.24. 330 lbs of ballast needed (without relocation of equipment) on baseline vehicle to get L/D to the minimum 0.27

C.G. very sensitive to packaging. Even with all packaging optimization including leaving empty volume on +Z side of aft bay, ballast may be needed to achieve minimum L/D

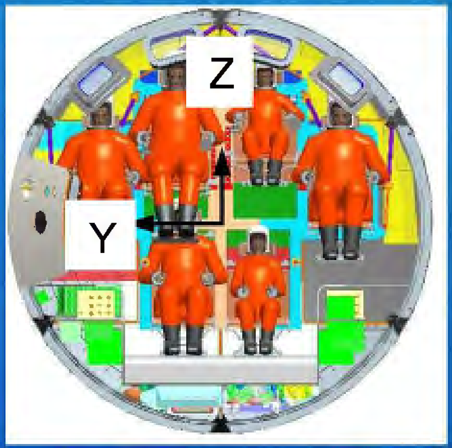
CM606C Internal Configuration Summary

- Changes to IML may have serious impact to vehicle performance
  - Tank size, parachute packing density, MMOD gap, heat shield material all affected by an IML change
- Current avionics & ECLSS components need to be inside pressurized vessel
  - Weight of cabling, ducting & tubing, pass-thru panels would drastically increase if any equipment were moved outside. Inefficient packaging would complicate manufacturing & maintainability. Equipment will have to be designed for a tougher environment, won't be accessible on pad or on orbit & will not be reusable (cost)
  - Room to move only 2 RIUs & some minor equipment into aft bay but that will affect CG
- Avionics & ECLSS volume allocation
  - 1–1.5" of avionics sway space allocated to accommodate shock & vibe environments
  - ECLSS packaging tight, currently reviewing need to increase ECLSS volume allocation by moving small ECLSS valves into avionics wings
  - Access to equipment in O&C, on pad & onorbit adds additional packaging constraints



CM606C Internal Configuration Summary (cont.)

- Crew size
  - Suit size
  - 3% spinal growth
- Seat stroke & crew spacing
  - Combination of 8" of Z stroke, seat pan thickness, spinal growth & 1.5" gap between top of lower crew's helmet & upper crew's head drives Z crew spacing. Assumes lower crew legs are brought up halfway between Shuttle & Soyuz style seats
- CM CG location
  - Drives dense avionics, ECLSS, heavier crew stowage to be located in –Z direction
  - Current lunar design needs 330 lbs of ballast to achieve minimum 0.27 L/D, 0.3 L/D desired. 550 lbs needed for ISS mission to offset crew members 5 & 6 & replacement of ECLSS wax pack with Freon system. CG will not be met if equipment is removed from floor without more weight allocation for ballast



Design Constraints

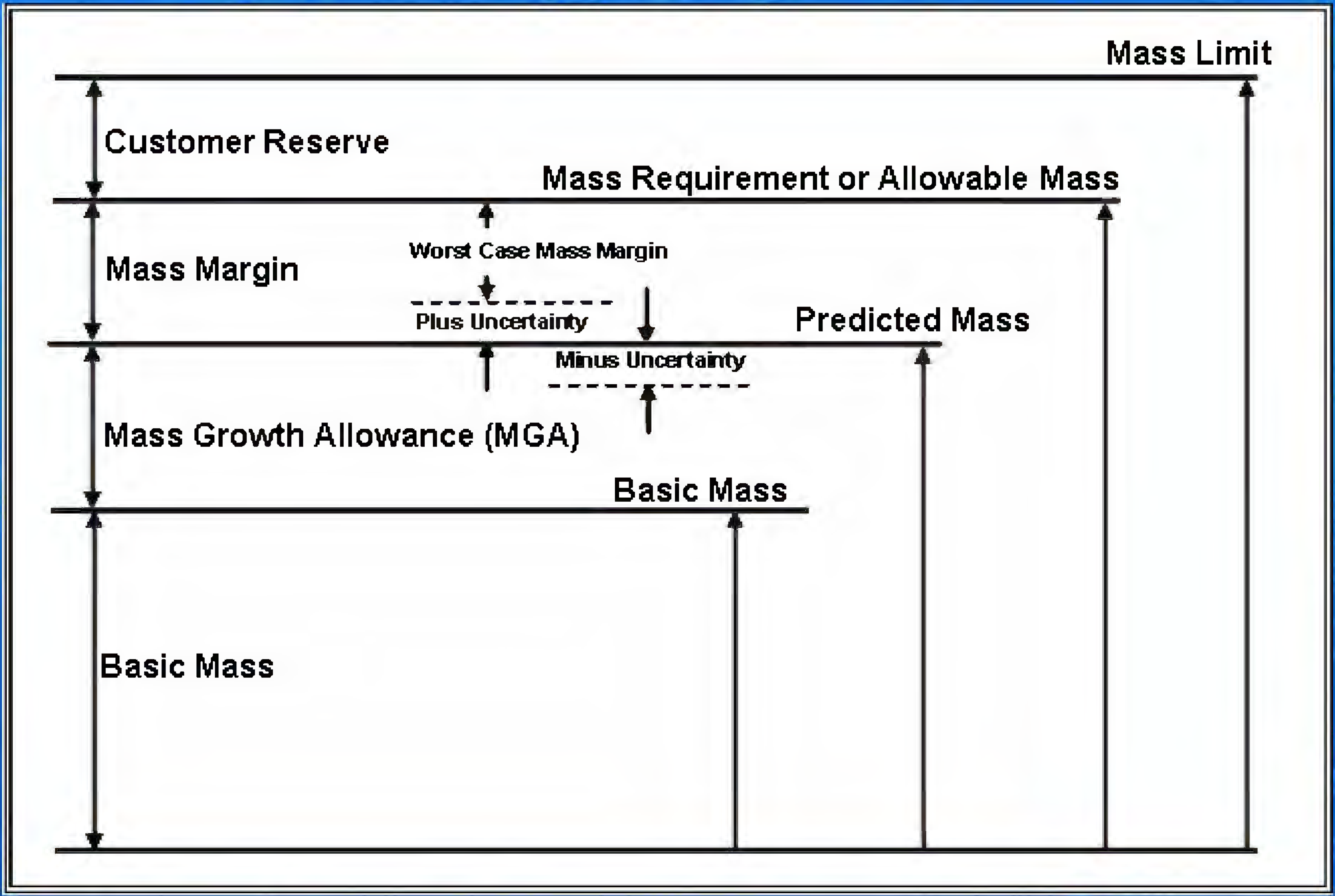
Bounding Requirements (1 of 2)

- Orion vehicle design: 6-person configuration (606C) with exception:
  - Heat shield shall remain mated to vehicle for landing event. Design options should consider rigidly attached heat shield with attenuation through 6 hard points or unlocked heat shield to allow for more energy attenuation through heat shield. Analysis should proceed with evaluation of both configurations: hard attach at 6 hard points or with ability to attenuate through hard point(s)
- Cannot significantly change CM pressure vessel inner mold line (IML)
- Cannot change crewmember's #1 & #2 eye position
  - This eye position has fixed CM windows & console. There is significant impact to system design if these items are to change
- Ingress & egress with incapacitated crew
  - Needs to be considered in seat & system design
  - Engineering/astronaut evaluations of mock-ups provide input

Bounding Requirements (2 of 2)

- Mass properties constraint is to keep Crew Module (CM) effective payload mass (EPM) below 21,000 lbs including mass growth allowance (MGA) & MR
- For comparison purposes, 606C seat & pallet masses are assumed to be:
  - ISS 6-person pallet (includes frame & struts): 511 lb
  - Lunar 4-person pallet (includes frame & struts): 449 lb
  - Seats (operators): 53.2 lb each
  - Seats (nonoperators): 36.3 lb each
  - NOTE: All numbers include mass growth allowance (MGA)

Mass Budget (Ref. AIAA S-120-2006)



Mass Growth Allowance (Ref. AIAA S-120-2006)

Table 1 — Mass Growth Allowance and Depletion Schedule

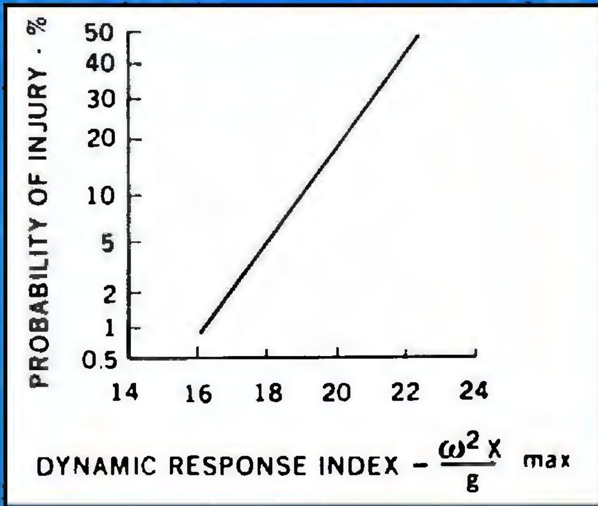
Major Category	Maturity Code	Design Maturity (Basis for Mass Determination)	Mass Growth Allowance (%)												
			Electrical/Electronic Components			Structure	Brackets, Clips, Hardware	Battery	Solar Array	Thermal Control	Mechanisms	Propulsion	Wire Harness	Instrumentation	ECLSS, Crew Systems
			0-5 kg	5-15 kg	>15 kg										
E	1	**Estimated** 1) an approximation based on rough sketches, parametric analysis, or undefined requirements, 2) a guess based on experience, 3) a value with unknown basis or pedigree.	30	25	20	25	30	25	30	25	25	25	55	55	23
E	2	**Layout** 1) a calculation or approximation based on conceptual designs (equivalent to layout drawings), 2) major modifications to existing hardware	25	20	15	15	20	15	20	20	15	15	30	30	15
C	3	**Preliminary Design** 1) calculations based on a new design after initial sizing but prior to final structural or thermal analysis, 2) minor modification of existing hardware	20	15	10	10	15	10	10	15	10	10	25	25	10
C	4	**Released Design** 1) calculations based on a design after final signoff and release for procurement or production, 2) very minor modification of existing hardware, 3) catalog value	10	5	5	5	6	5	5	5	5	5	10	10	6
A	5	**Existing Hardware** 1) actual mass from another program, assuming that hardware will satisfy the requirements of the current program with no changes, 2) values based on measured masses of qualification hardware	3	3	3	3	3	3	3	2	3	3	5	5	4
A	6	**Actual Mass** measured hardware	No mass growth allowance – use appropriate measurement uncertainty values												
A	7	**Customer Furnished Equipment or Specification Value**	Typically a "not-to-exceed" value is provided; however, contractor has the option to include MGA if justified												

Contingency Land Landing (CLL) Assumptions

- Crew health: For analysis purposes, assume CLL occurs with de-conditioned long duration crew. H&M ITA ACTION: Provide definition of "deconditioned crew"
- Contingency land landing assessments should use Brinkley low as default criteria for analyses
- Environmental conditions & vehicle assumptions (design to drivers):
  - Horizontal velocity: 0–60 fps in 10-fps increments
  - Land slope: 0 & 5°
  - Soil: Hard packed & dry loose sand per NASA Langley LS/Dyna soil models. Hard packed representative to hardest dry lakebed conditions. Dry loose sand representative to beach conditions
  - 7 evaluation load cases provided (3 land, 3 water landings & 1 tumble)

Brinkley Criteria

Multiaxial dynamic response criteria
Normal & deconditioned injury risk levels

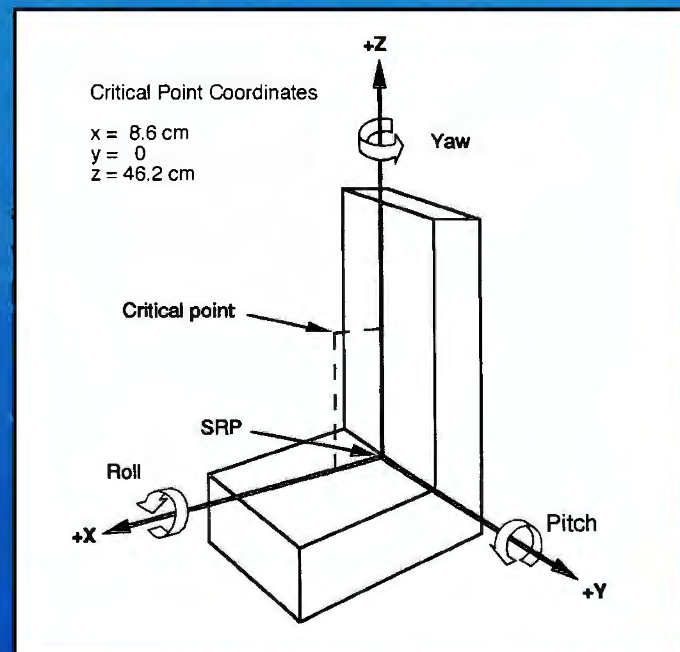


- Initial estimates based upon breaking strength of cadaver vertebrae
- Probability distribution adjusted to higher values based upon operational ejection seat experience

Normal Risk Level			Low	Moderate	High
Deconditioned Risk Level		Low	Moderate	High	
DRXL	DRX> 0	31.0	35.0	40.0	46.0
	DRX< 0	22.4	28.0	35.0	46.0
DRYL	CR*	11.8	14.0	17.0	22.0
	SP**	12.5	15.0	20.0	30.0
DRZL	DRZ> 0	13.1	15.2	18.0	22.8
	DRZ< 0	11.0	13.4	16.5	20.4

Dynamic response (DR) index limits

***CR = Conventional restraint, **SP = Side panels**



Coordinate system

Assessment Load Cases (3)—Contingency Land Landing

Contingency land landing (CLL):

Matlab Case Number "CLL_Data.mat"		Input conditions: CM Pitch deg	Vertical Vel fps	Horiztontal Vel fps	CM Roll deg	Ground Model	Ground Slope (deg)	CM Materials	Results as of 12/14/2007. Model removes 6 pt stiff load path from HS to CIA config 'CIA8' which adds 1 Y strut near the middle of pallet. CG Accelerations (X1=first impact, X2=second impact, same for Z1/Z2): X	X1	X2	Y	Z	Z1	Z2	Peak RSS: RSS
	High Pitch Angle (33°)								28.3	14.0	28.7	1.5	31.6	31.7	8.0	31.6
⇒ 15	44072	33	24	0	0	hard soil	0	non-linear	**28.3**	14.0	28.7	0.9	23.0	22.8	-15.0	30.4
16	44078	33	24	10	0	hard soil	0	non-linear	23.1	11.0	23.1	0.9	25.2	25.2	-13.0	27.2
17	44074	33	24	20	0	hard soil	0	non-linear	17.8	11.0	18.4	0.9	25.6	25.4	5.0	27.4
18	44080	33	24	30	0	hard soil	0	non-linear	14.3	10.0	14.3	1.4	28.2	28.2	5.0	29.8
19	44076	33	24	40	0	hard soil	0	non-linear	14.3	10.0	14.3	1.5	29.4	29.4	7.0	30.7
20	44082	33	24	50	0	hard soil	0	non-linear	14.1	10.0	14.1	0.9	29.7	29.7	8.0	31.0
⇒ 21	44084	33	24	60	0	hard soil	0	non-linear	14.1	10.0	13.7	0.9	**31.6**	31.7	8.0	31.6
	30 Deg Roll Cases															
22	44032	28	24	0	30	hard soil	0	non-linear	22.3	15.0	22.3	12.1	21.5	21.5	-9.0	28.3
⇒ 23	44034	28	24	20	30	hard soil	0	non-linear	20.3	15.0	20.4	**14.3**	25.4	25.0	3.0	32.7
24	44036	28	24	40	30	hard soil	0	non-linear	18.1	15.0	18.1	14.6	25.5	25.5	3.0	32.9
25	44044	28	24	60	30	hard soil	0	non-linear	18.2	15.0	18.2	14.4	25.1	25.1	3.0	32.4

Tumble load case:

	Roll (deg)	Pitch (deg)	Horiz Vel (fps)	Vertical Vel (fps)	Max CM CG Acceleration (g): X	Y	Z
44023	180	28	40	24	61.8	3.8	47.3

Assessment Load Cases (3)— Water Landing

606C CEV FEM (4XXXX Series) DAC2 Design Cases					
Matlab Case Number "Water_Data.mat"	DAC2 Case No.	MC Case No. (Ref)	CG Acceleration (G) X-axis	Y-axis	Z-axis
	Nominal Water Landing, Pacific Full Chutes (42		16.0	2.3	7.9
1	**42000**	1192	11.8	1.0	4.7
2	**42001**	1847	16.0	1.2	7.7
3	**42002**	1495	11.9	2.3	7.9
4	**42003**	572	5.7	1.3	5.5
5	**42004**	573	2.7	0.7	5.0
6	**42005**	640	1.3	0.5	4.0
	Off-Nominal Water Landing, Pacific 1 Chute Ou		25.8	3.2	12.0
7	**42200**	120	**25.8**	1.4	8.5
8	**42201**	1849	24.1	1.5	10.1
9	**42202**	929	22.7	2.3	**12.0**
10	**42203**	475	8.9	3.2	9.6
11	**42204**	97	3.2	1.3	6.7
12	**42205**	556	1.9	0.8	6.2
	Off-Nominal Water Landing, Ascent Abort Nor		20.3	3.4	9.6
13	**42300**	1192	7.7	0.8	2.0
14	**42301**	1847	20.3	1.5	8.4
15	**42302**	1495	18.1	**3.4**	9.6
16	**42303**	2066	4.9	0.8	6.7
17	**42304**	573	2.4	1.0	7.1
18	**42305**	799	2.4	2.6	6.8

Contingency Land Landing (CLL) Assumptions Notes

1. Not necessary to assess obstructions, ditches, or ground fires that might result from abort
2. Initial Orion project contingency land landing evaluations planned:
   a. Contingency land landing conditions above with nominal vehicle performance (i.e., 3 chutes, 28° hang angle & roll control available with 6-person configuration)
   b. Contingency land landing conditions above with following "roll control fail" cases:
      i. ±90° (side impact) & 180° (head first)
3. Future evaluations may be run for single chute out or additional failure cases depending upon architecture status ERB results/recommendations

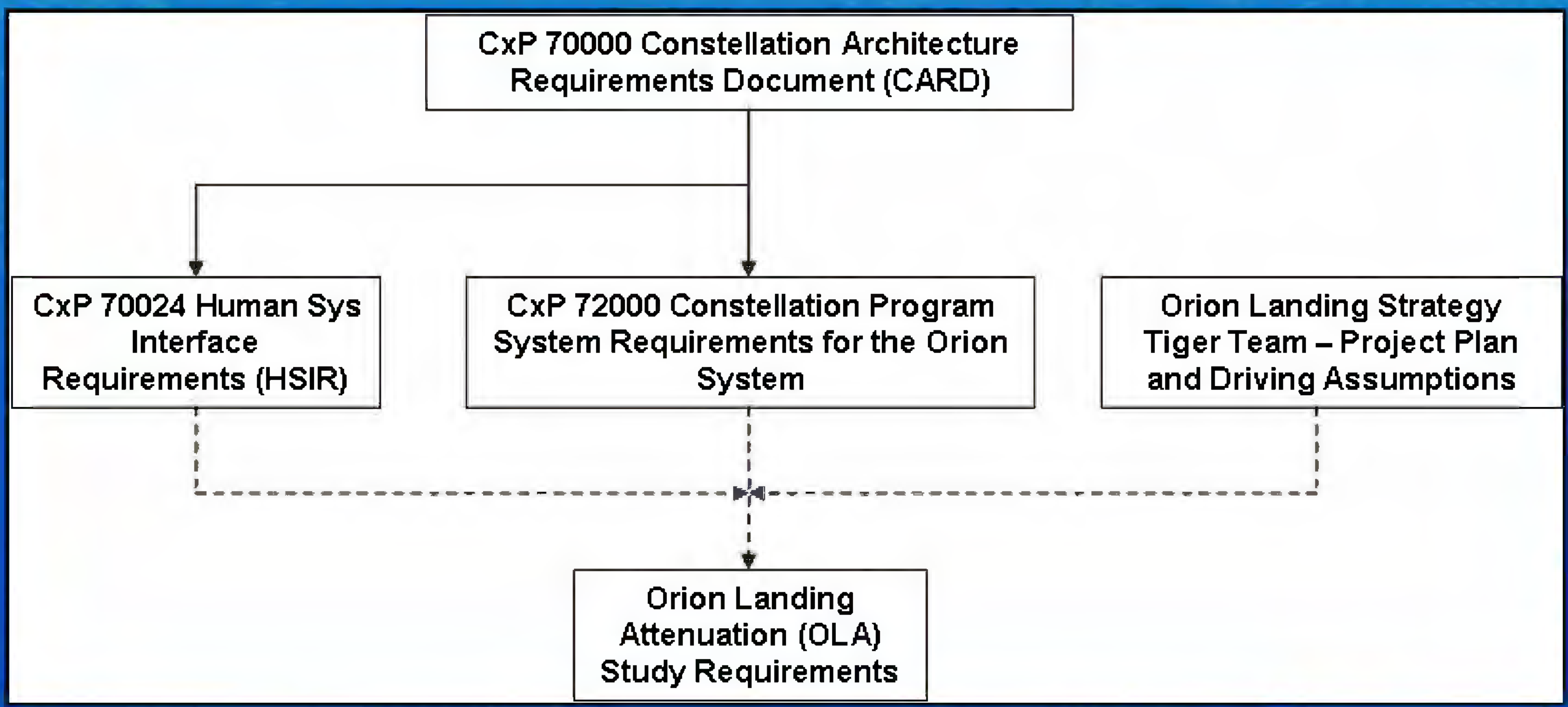
Contingency Land Landing (CLL) Assumptions Notes (cont.)

4. Vehicle will likely tip over at some point during 0–60 fps analyses. When this occurs:
   a. Define what conditions cause it to tip over & provide rationale for cause of tip-over (e.g., wind & other environmental constraints & vehicle conditions like 28° hang angle) so mitigation methods may be investigated
   b. Design goal is to develop solution that protects crew in event vehicle tips over regardless of tip-over mitigation plan
5. It is desirable to assess a single run where struts may have bottomed out during run & rerun that same configuration with different stroke profile such that it doesn't bottom out (so that we can compare results)

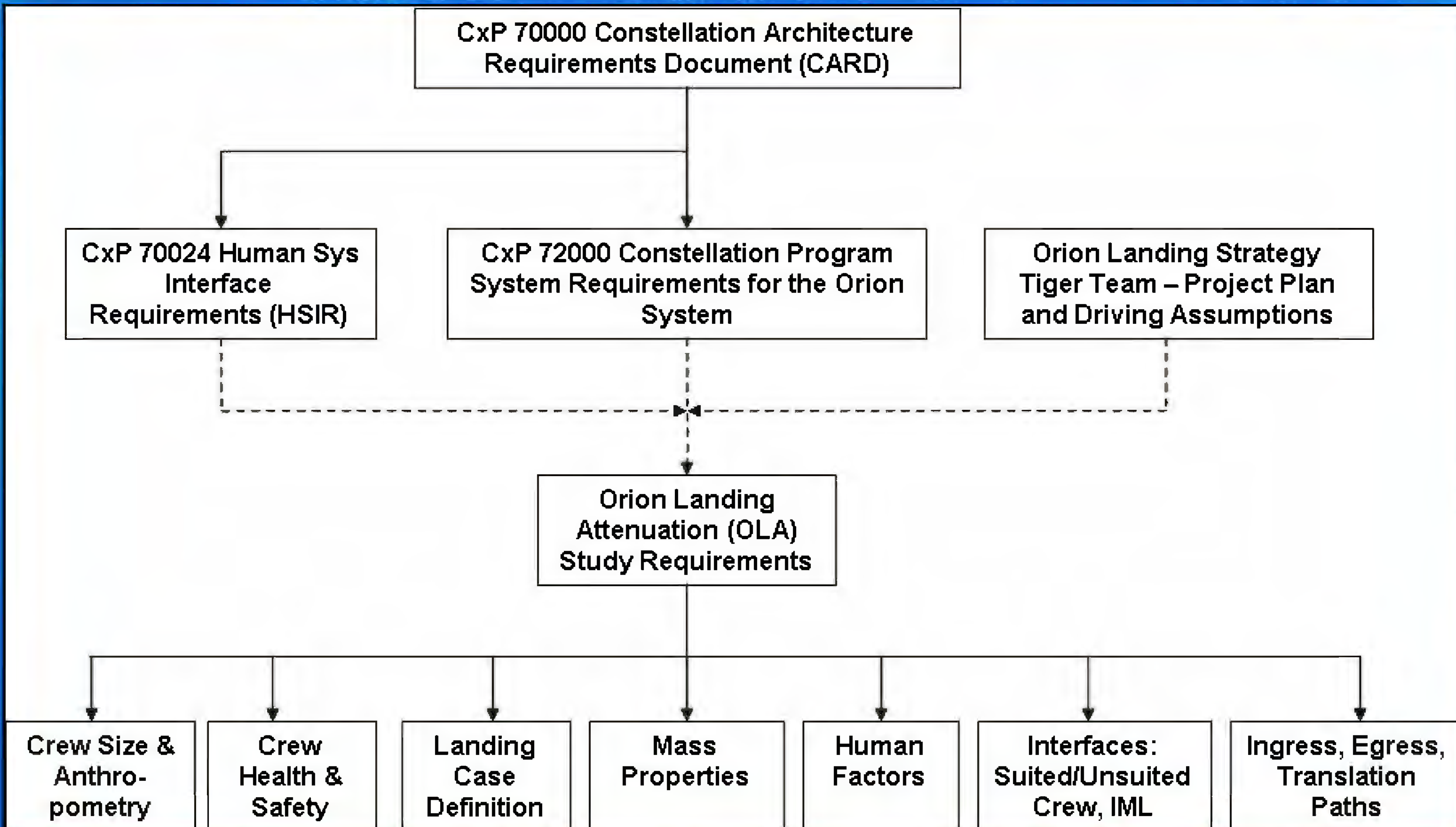
Requirements Compliance

Orion Landing Attenuation (OLA) Requirements Tree

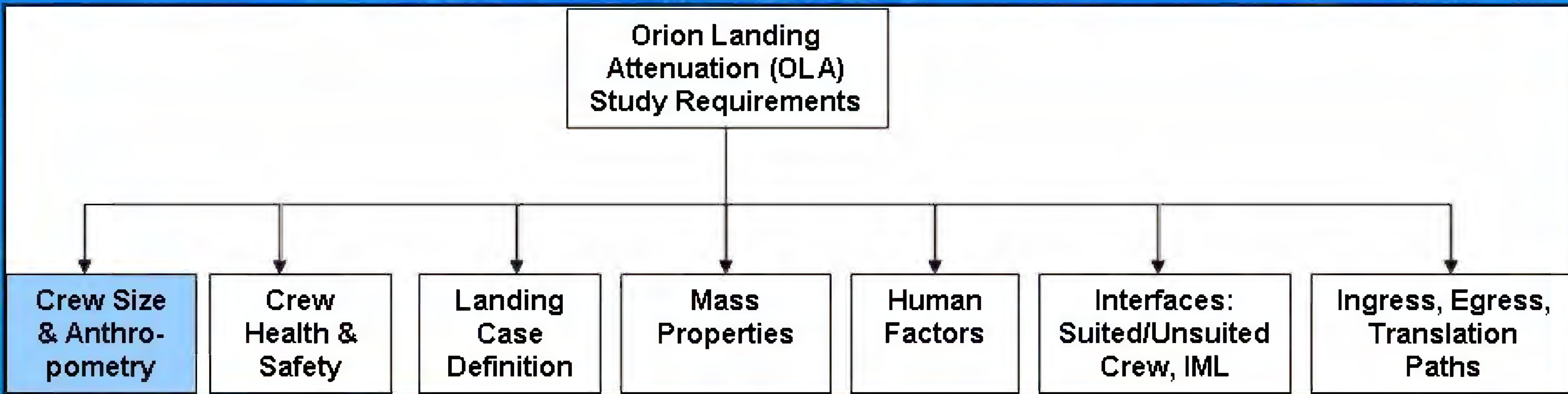
- Requirements applicability
  - CARD, SRD, HSIR & Steering Committee memo to identify requirements applicable to OLA design
  - Developed draft set of consolidated requirements for OLA design
  - Identified approach to assess OLA design compliance to requirements
  - Plan to continue to mature requirement set: “living document”



OLA Driving Requirements

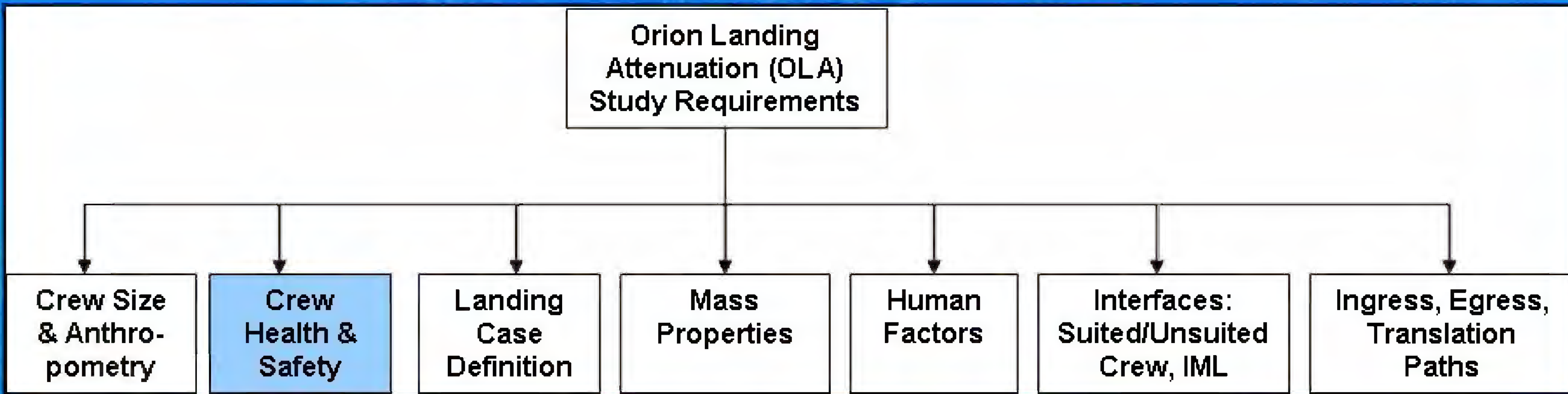


OLA Driving Requirements— Crew Size & Anthropometry



- 606C 6-person crew
- Anthropometric dimensions of suited crew
- Anthropometric dimensions of unsuited crew
- Range of motion of suited/unsuited crew

OLA Driving Requirements— Crew Health & Safety



- Injury protection during dynamic flight phases
- Injury protection during water & CLL cases
- Crew exposure to acceleration
- Crew exposure to vibration
- Crew protection from flail
- Crew protection post-landing (nominal & 36-hour)

OLA Driving Requirements—Landing Case Definition

Orion Landing Attenuation (OLA) Study Requirements

- Crew Size & Anthro-pometry
- Crew Health & Safety
- **Landing Case Definition**
- Mass Properties
- Human Factors
- Interfaces: Suited/Unsuited Crew, IML
- Ingress, Egress, Translation Paths

- 3 CLL cases
- 1 tumble case on land
- 3 water landing cases

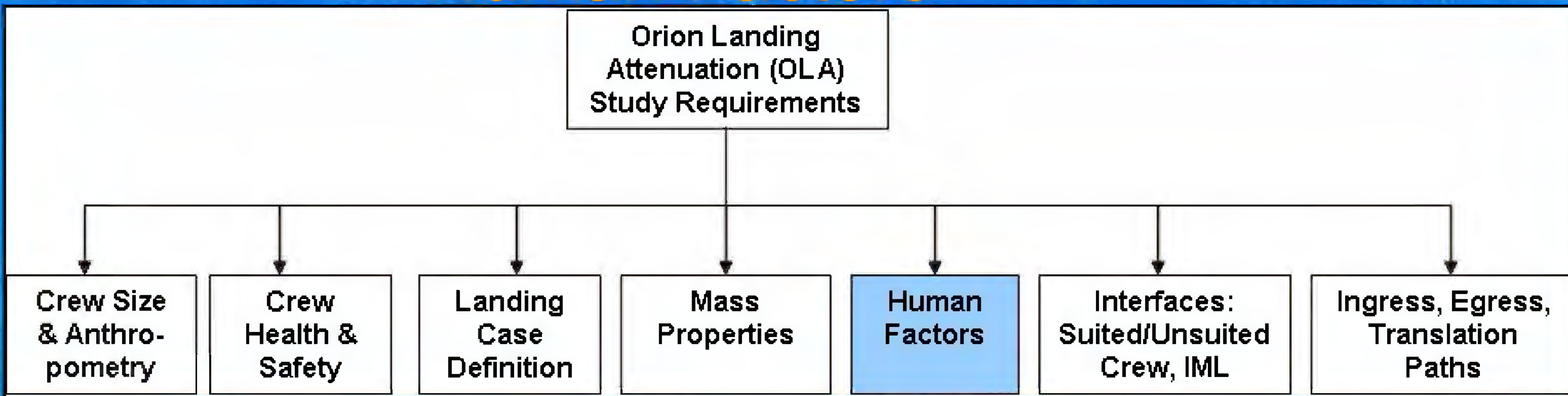
OLA Driving Requirements—Mass Properties

Orion Landing Attenuation (OLA) Study Requirements

- Crew Size & Anthro-pometry
- Crew Health & Safety
- Landing Case Definition
- **Mass Properties**
- Human Factors
- Interfaces: Suited/Unsuited Crew, IML
- Ingress, Egress, Translation Paths

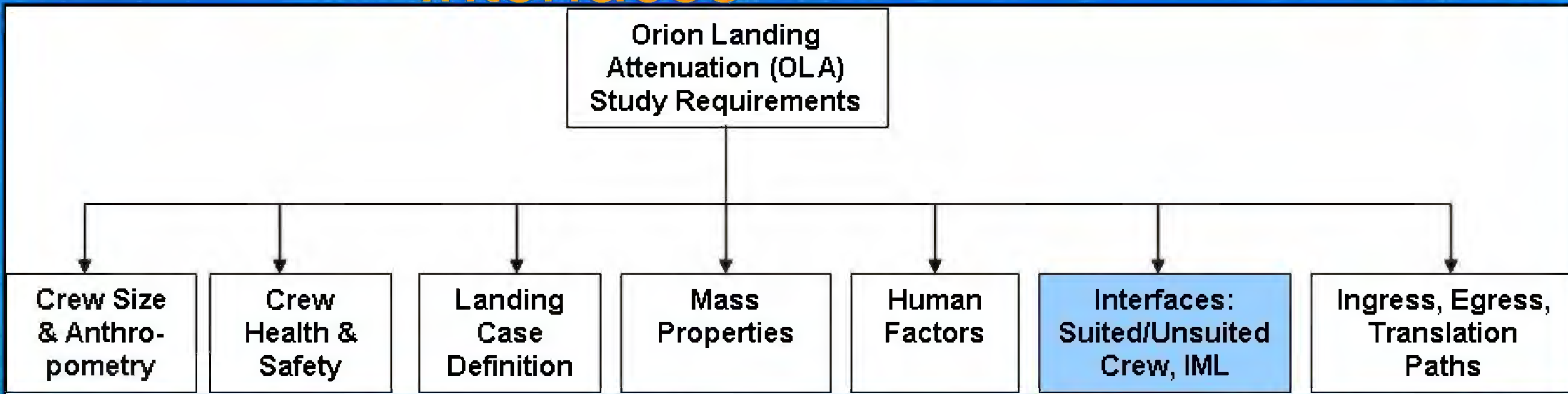
- Mass properties of suited/unsuited crew
- Mass properties of OLA design

OLA Driving Requirements—Human Factors



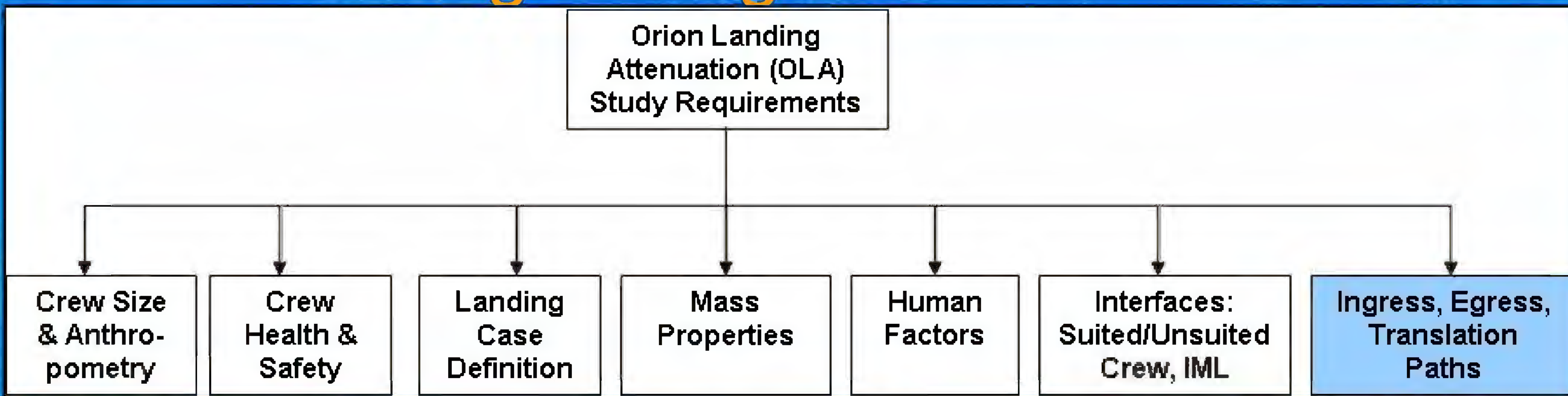
- Operator 1 & 2 eyepoint
- Access to display & controls
- Access to stowage
- Access to emergency equipment
- Operability (606C)
- High G operability
- Reconfiguration without tools
- Operating forces

OLA Driving Requirements—Interfaces



- Interface to IML
- Interface to unsuited crew
- Interface to ESR#2 EVA suit (waist ring eliminated)

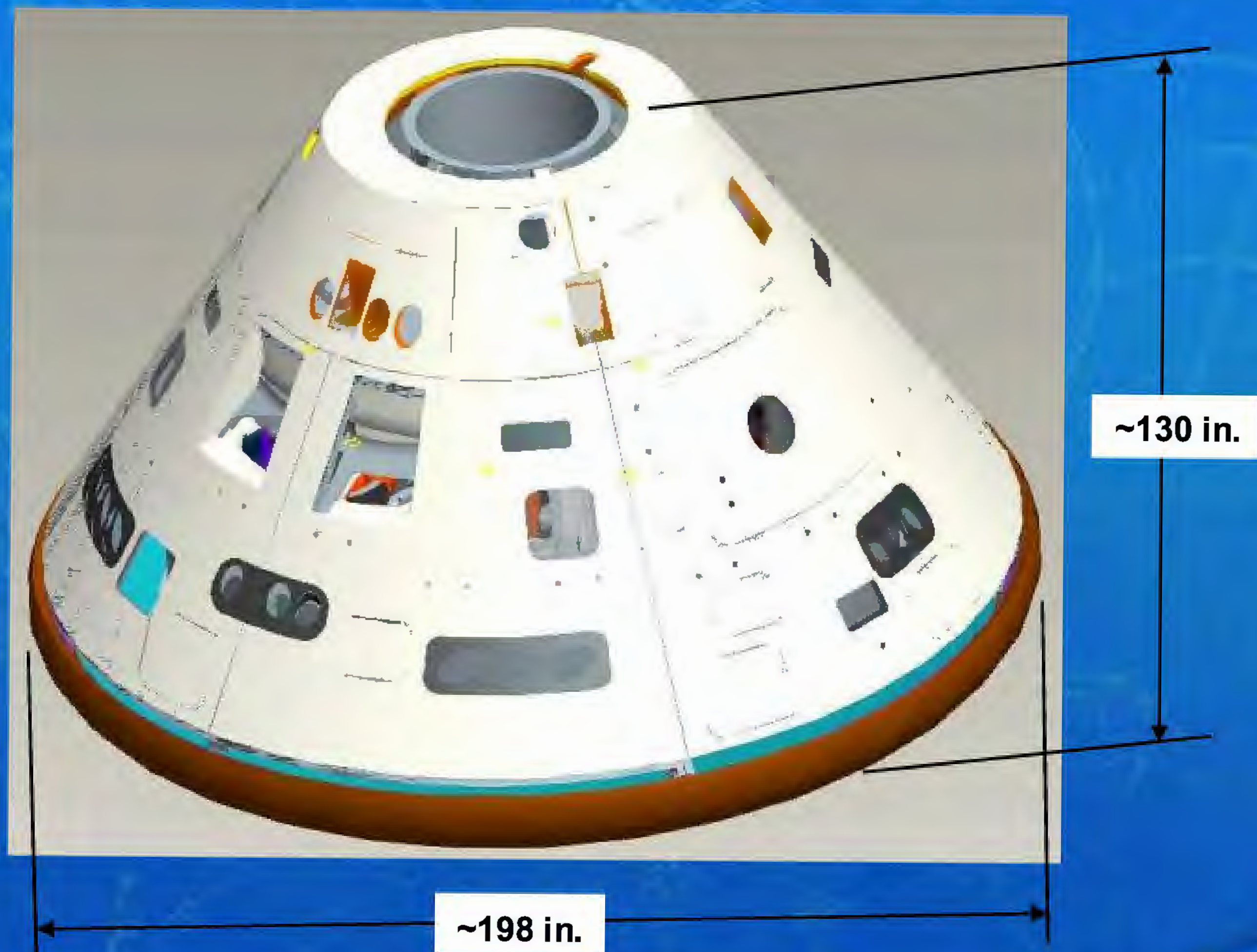
OLA Driving Requirements—Ingress/Egress



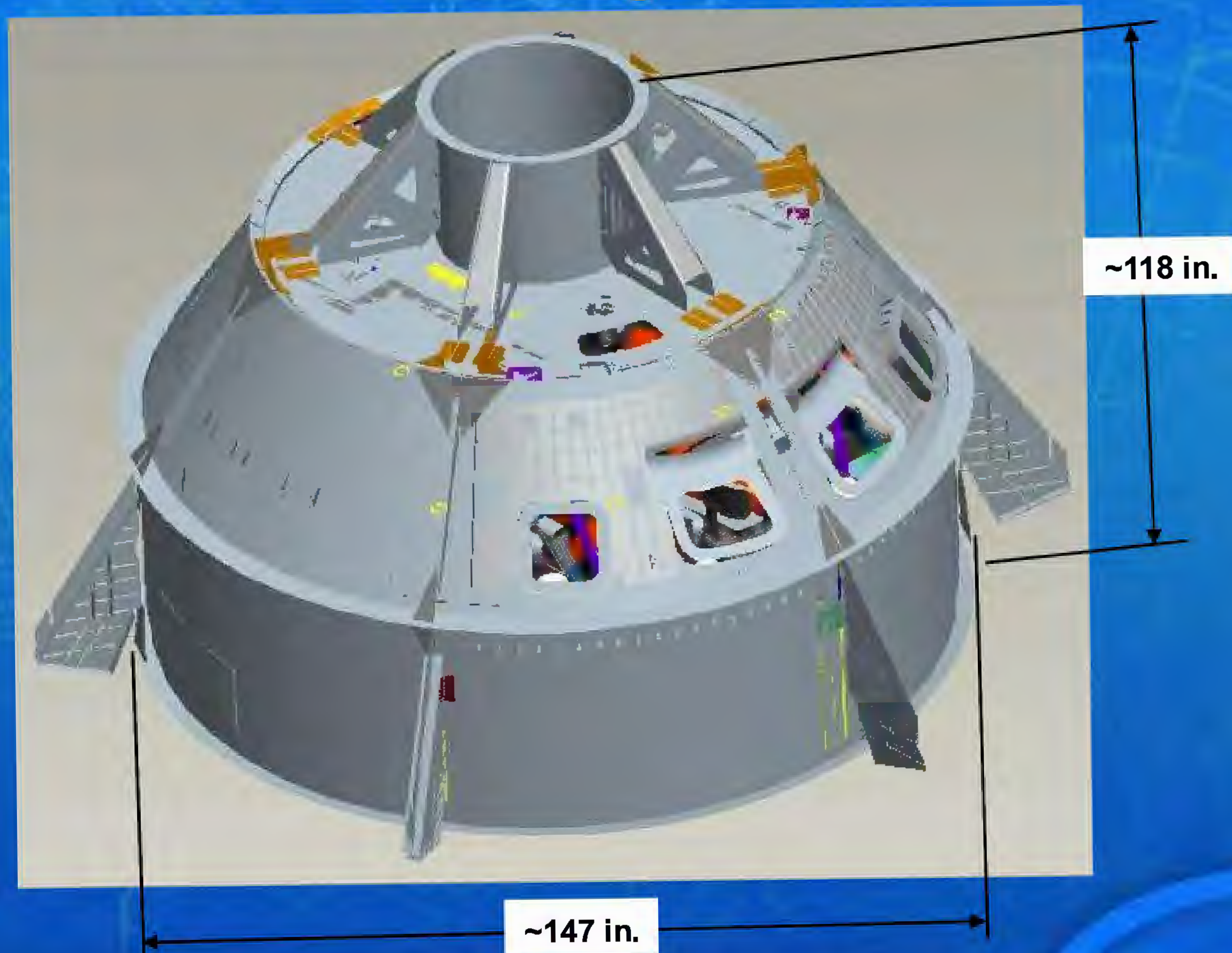
- Nominal ingress/egress
- Translation paths (ground & space)
- Emergency egress (pre-launch: crew & ground crew)
- Incapacitated crew rescue
- Post-landing emergency egress

Design Interface Description

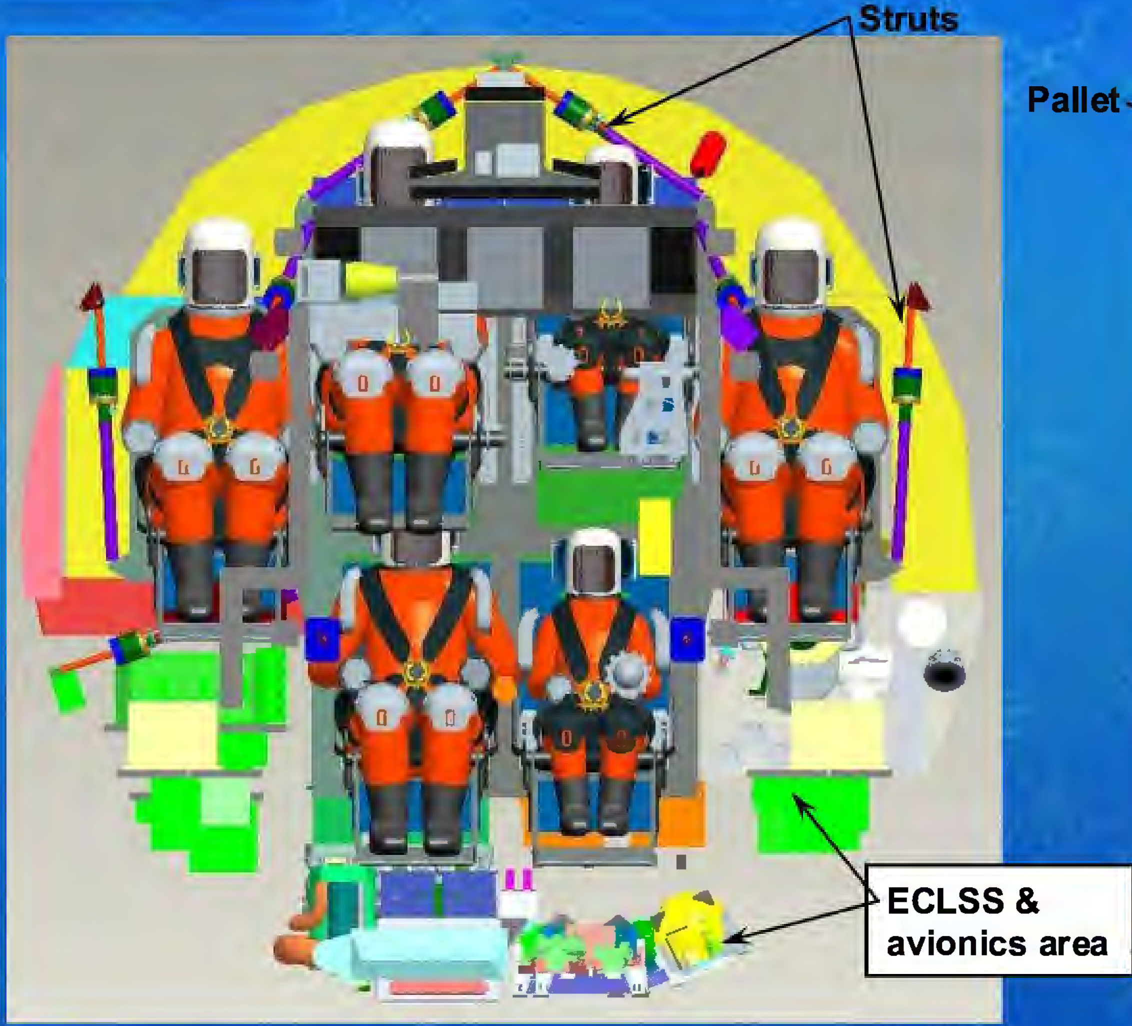
Orion CM External Configuration

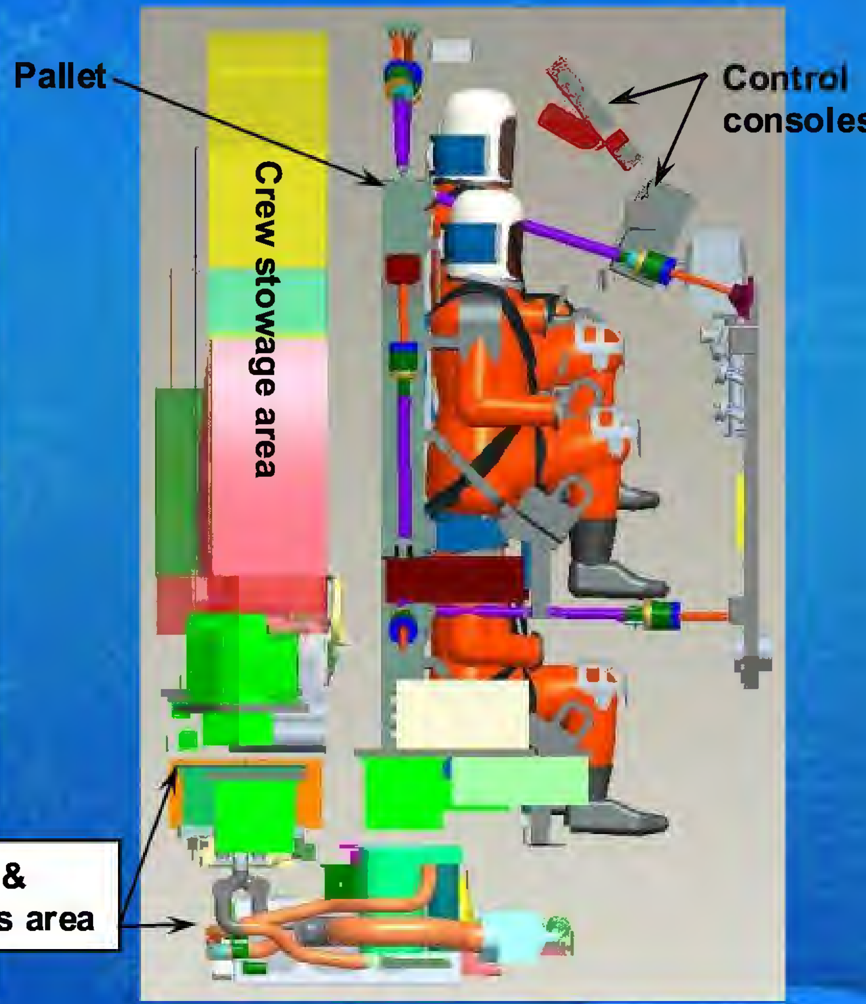


Orion CM External Pressure Vessel Configuration

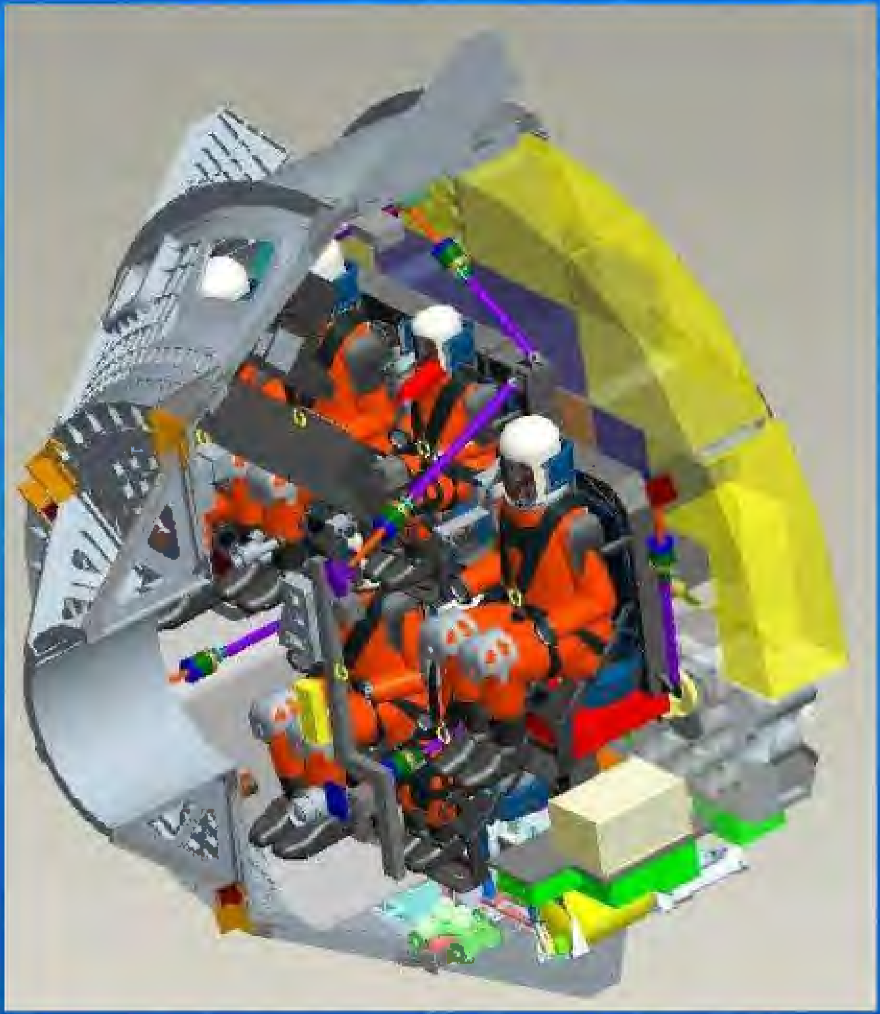


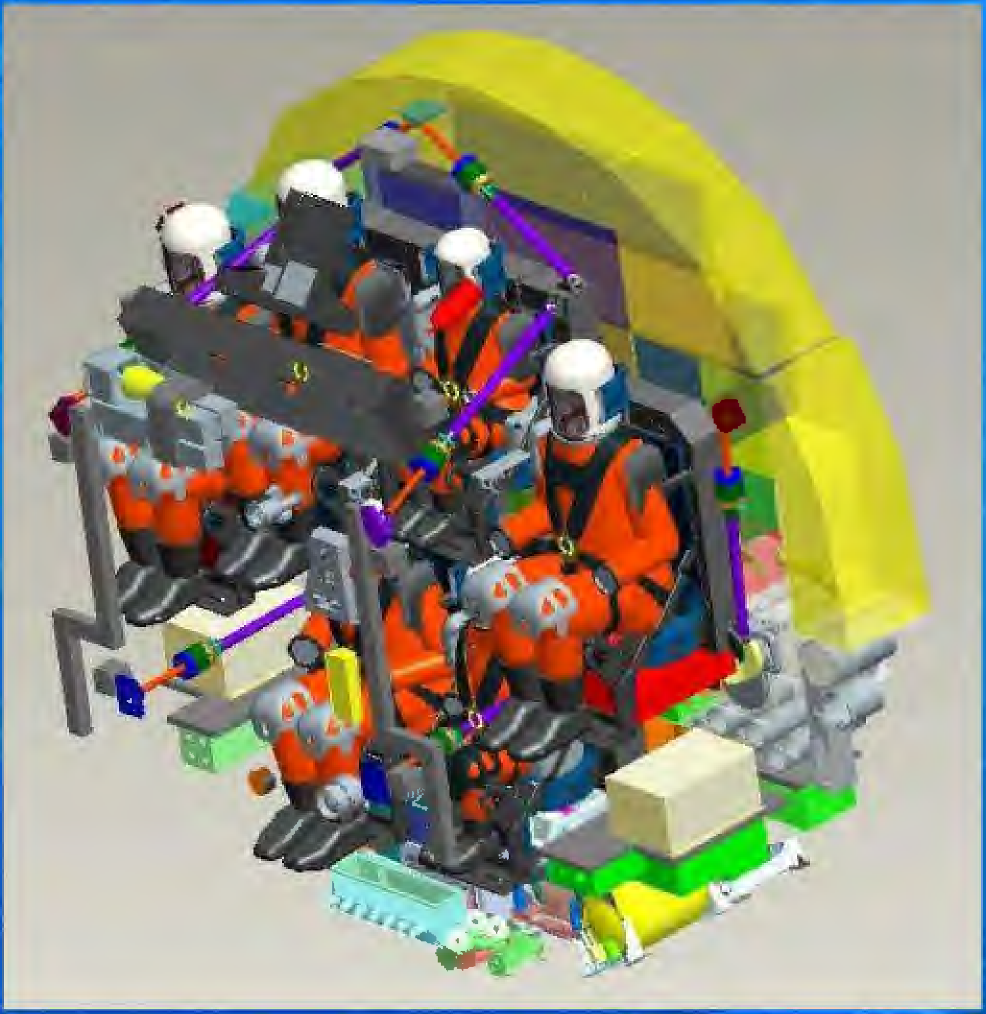
CM Internal Configuration (1 of 2)



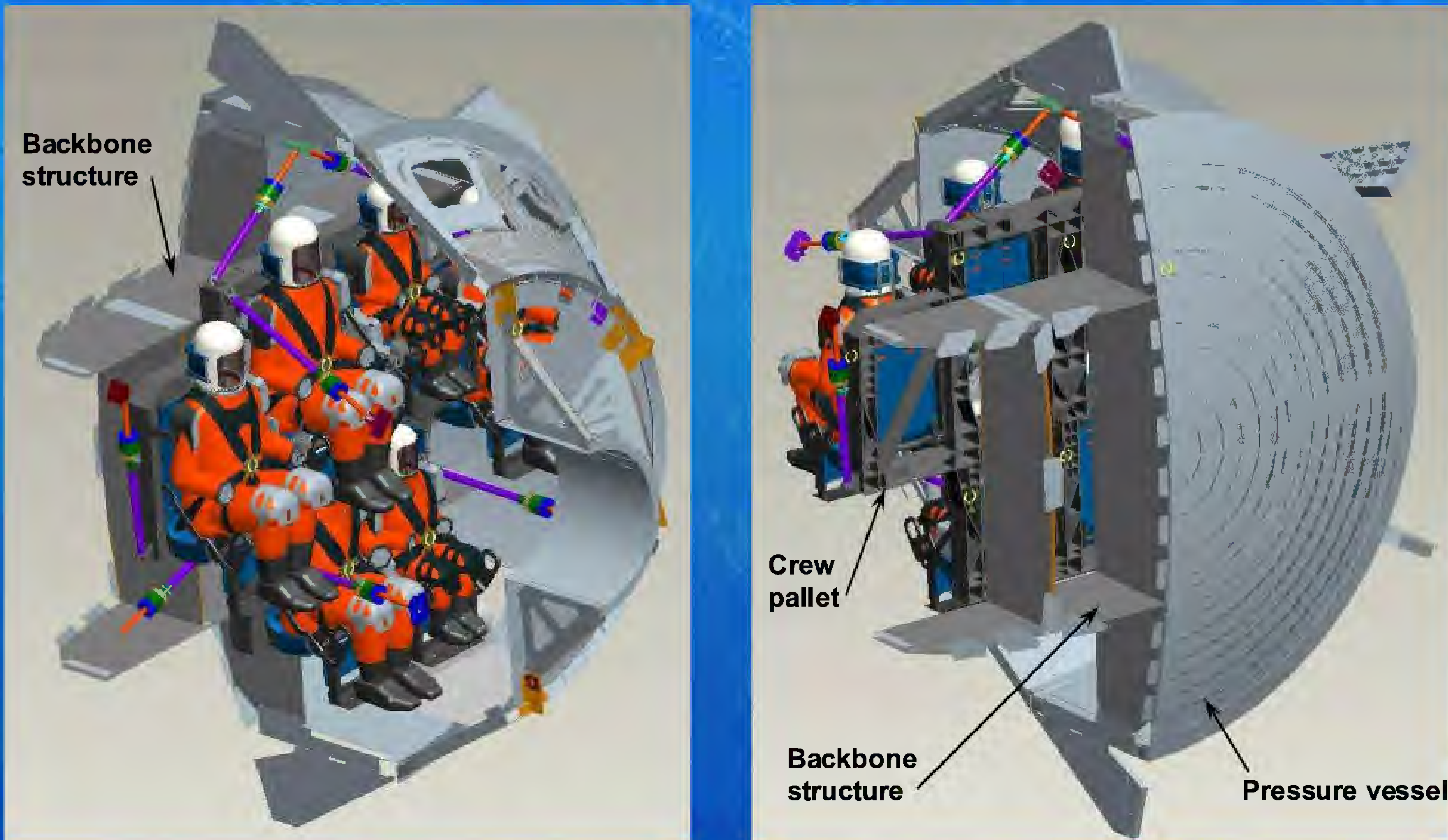


CM Internal Configuration (2 of 2)



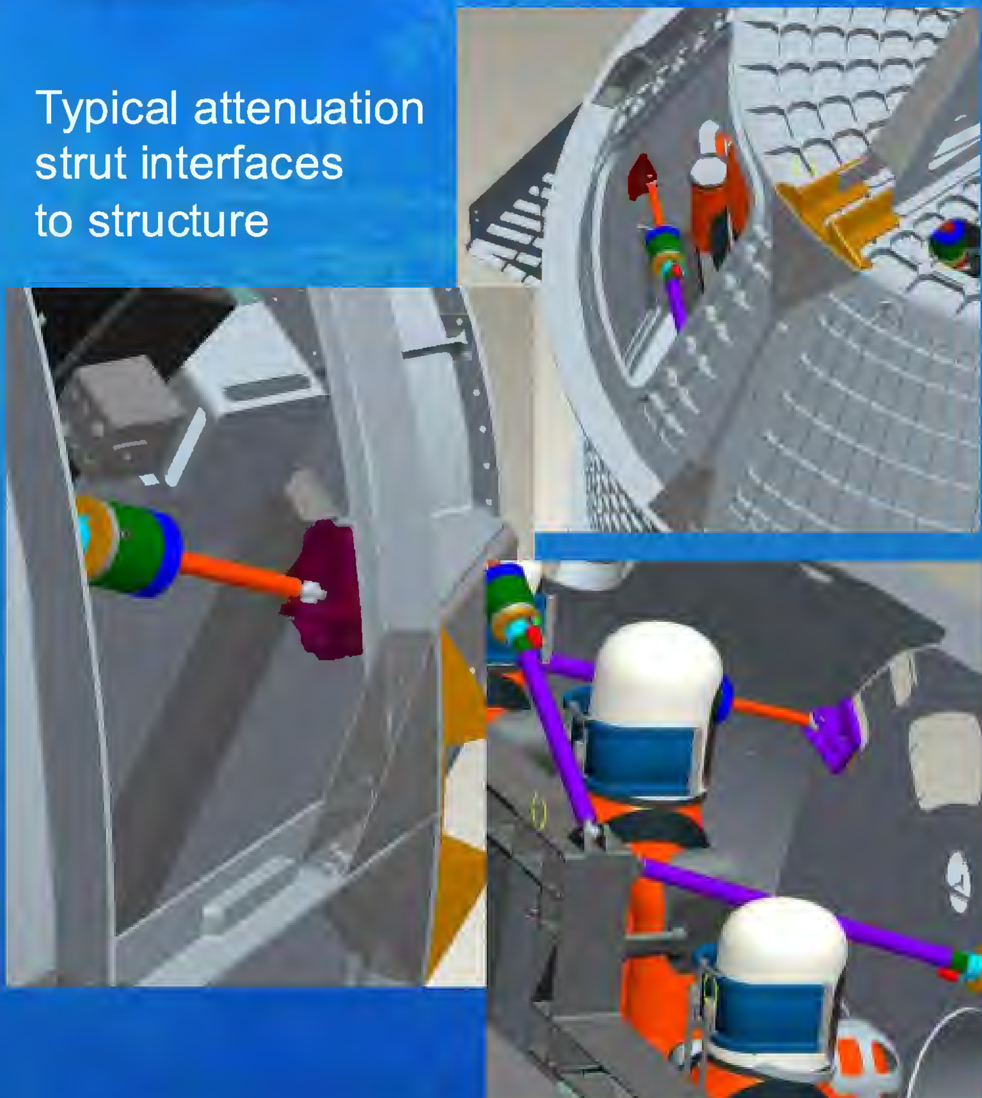


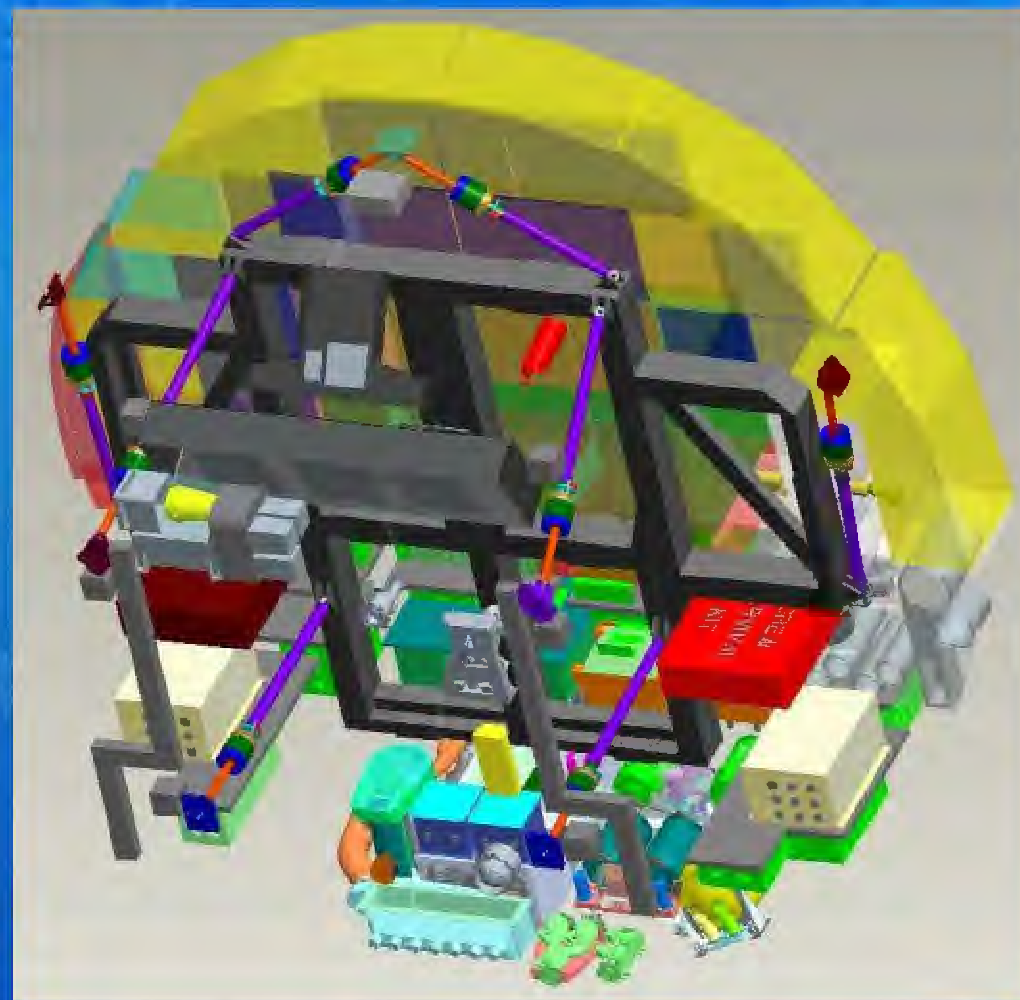
CM Internal Configuration—Structural Interfaces



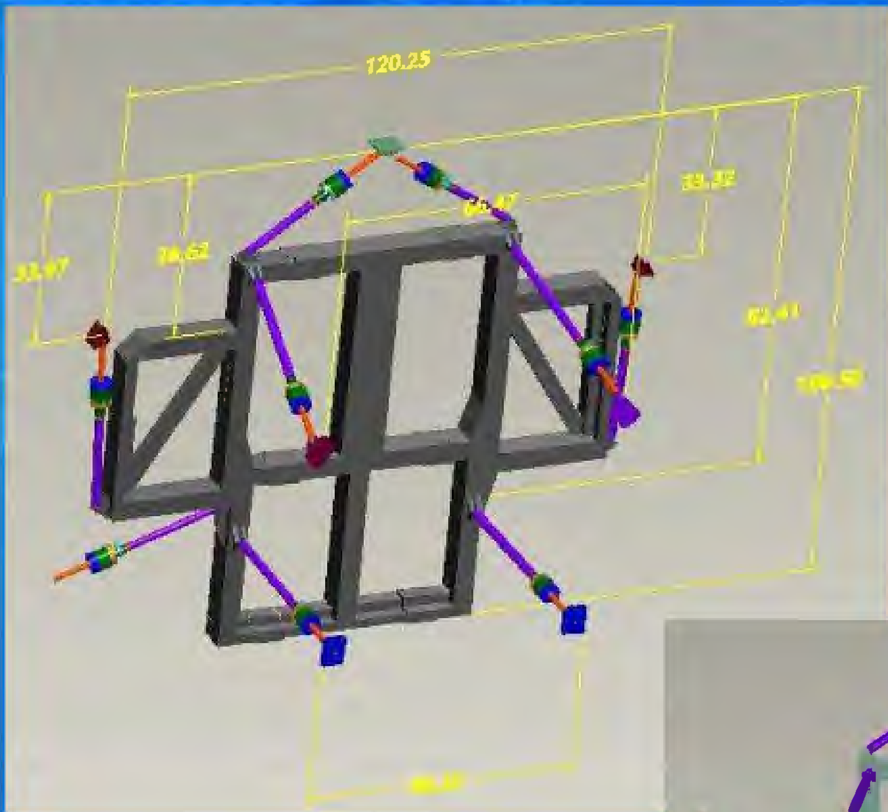
Pallet & Strut System Interfaces

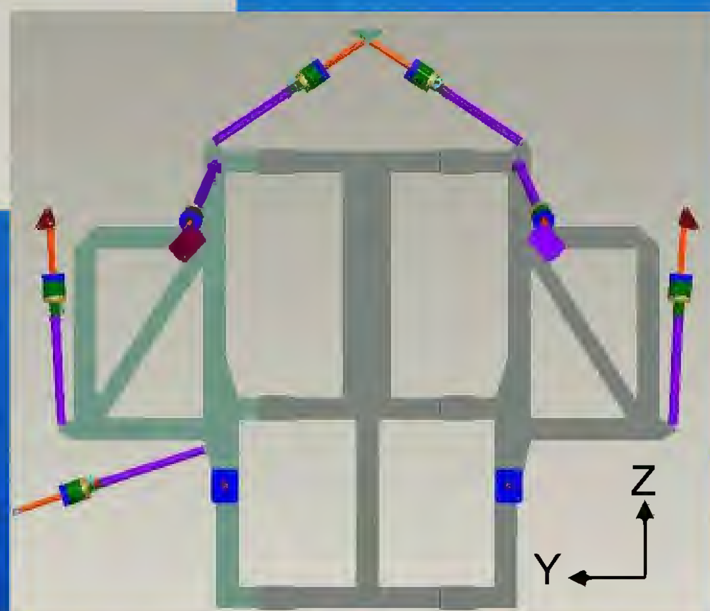
Typical attenuation
strut interfaces
to structure



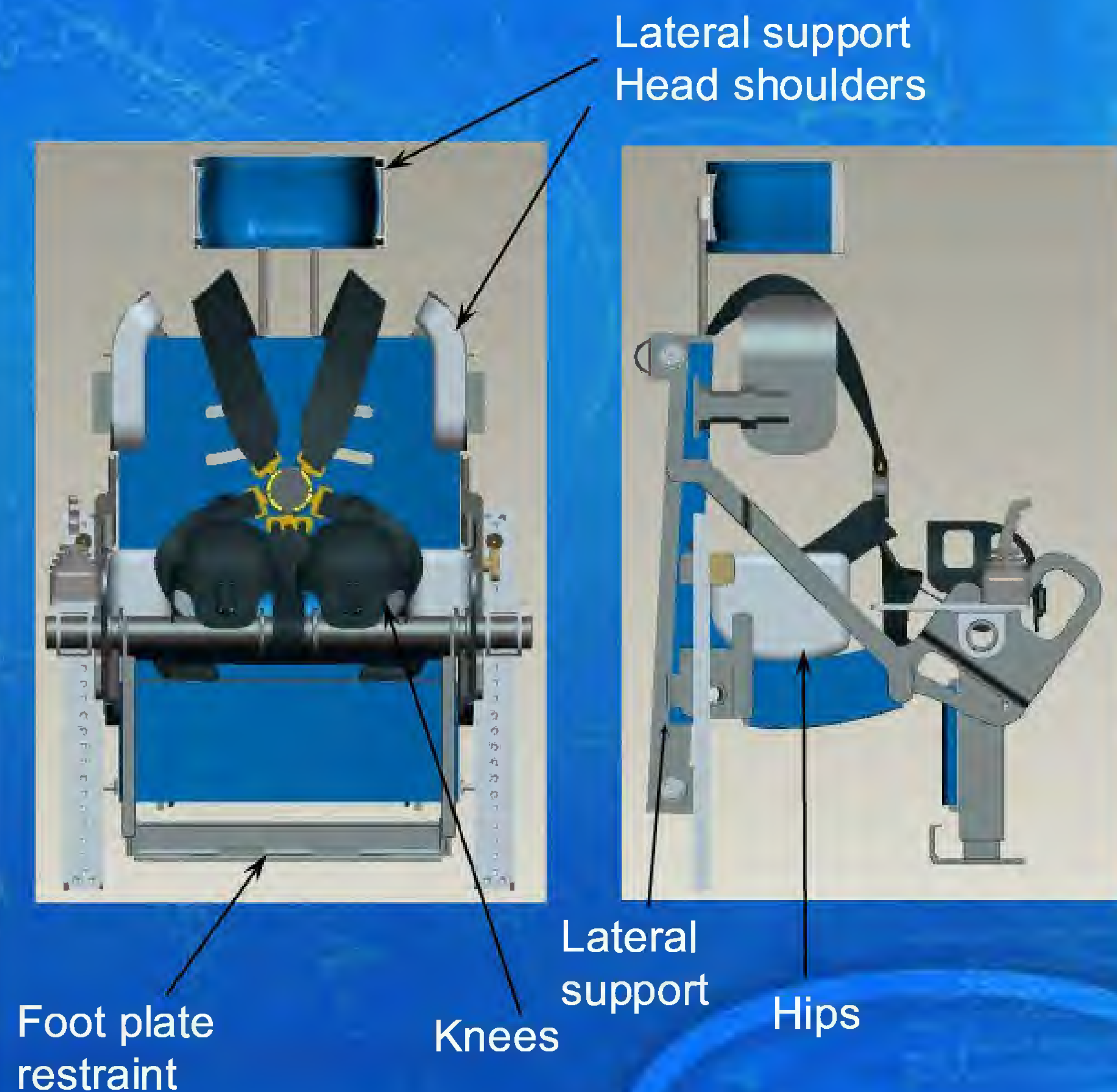


CM Pallet & Struts





CM Seat Design



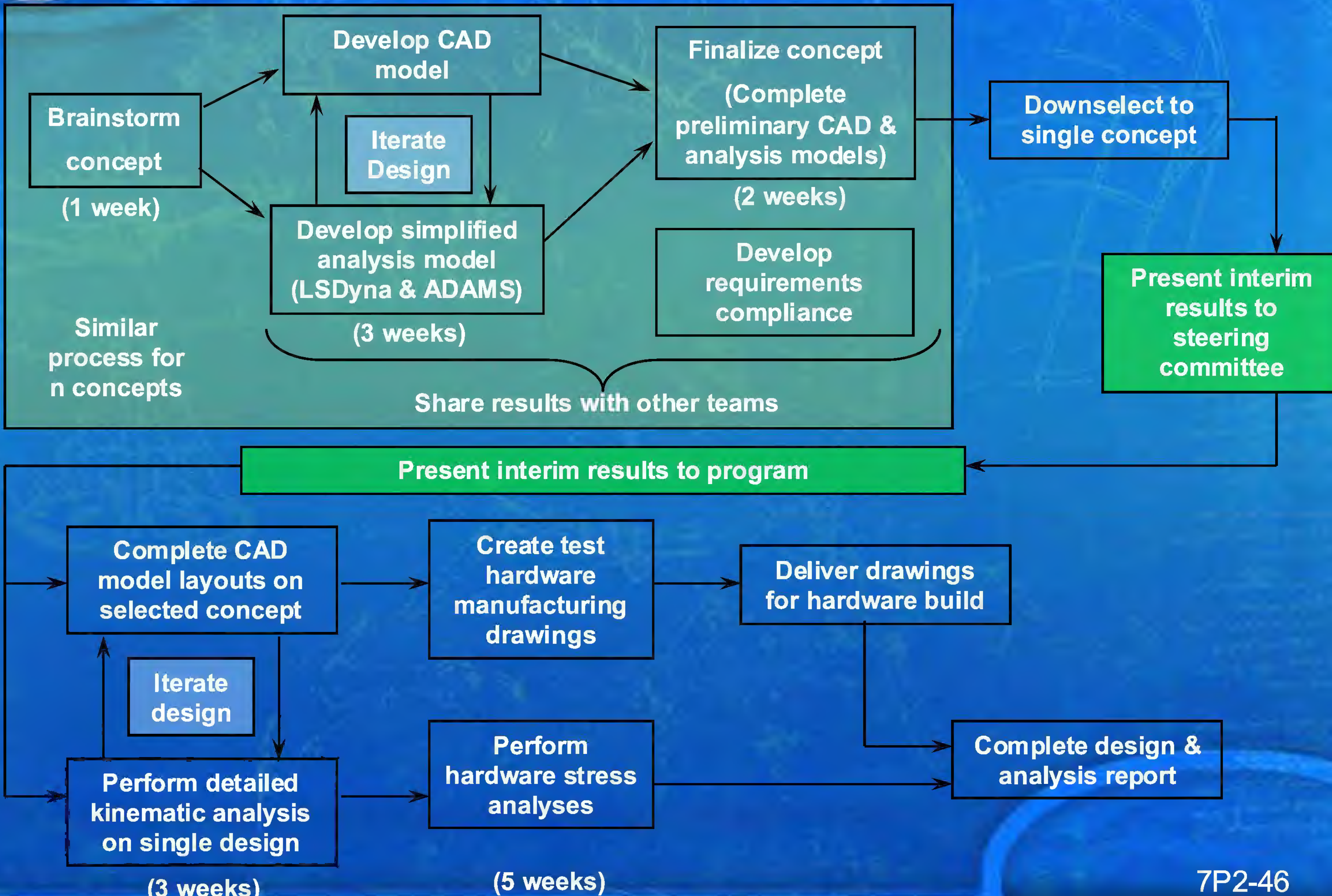
Analysis Tools

Design & Analysis Tools Used by NASA Team

- Design
  - Computer aided design (CAD)
    - ProEngineer used for all modeling & configuration management (Windchill Project Link)
  - Engineering tests
- Analyses
  - Excel
    - Simplified 2-DoF analyses
  - NASTRAN
    - Flexible body input
    - Hardware strength sizing
    - Frequency analysis
  - ADAMS
    - Reduced kinematic models
    - Full model system verification
  - LSDyna
    - Reduced kinematic models
    - Full model system verification
  - Brinkley model
    - Determine susceptibility to crew injury based on crew member acceleration

System Design Studies

NESC Team Operation Flow



What issues do you see with the NESC Team Operation Flow?

0% a. Concept development phase is not sufficiently focused

0% b. Concept development phase is too long

0% c. Concept development phase is too short

0% d. Requirement interaction is not sufficiently defined

0% e. Project Manager input is not frequent enough

0% f. Other (be prepared to discuss)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

Answer Now

10

Design Concept Definition Matrix

Investigated slight variation of these concepts based on continued information flow (design, analysis & test data from previous efforts)

Combined into primary design (Concepts #1–#2)

Promising but lowest priority for investigation due to resource limitations (Concept #4)

Struts and Inteface to Pallet	Pallet & Interface to Seat	Seat & Interface to Crew
Concept #1		
Fix Pallet interface to backbone in X & Y, slip mechanism for Z motion.	Rigid fixed interface of seat to pallet	Foot & Knee Position like Soyuz (with the ability to stretch legs and strap down shortly before Launch & Landing)
Concept #2		
Raise head of pallet and and swing in XZ (Pivot at Crew feet) - possibly use a rotary attenuation system.	Small Stroke ability for X & Y if required.	NASCAR-Type bucket seat with adjustable foot plate and back length. (i.e. adjust shoulder/head support - PR); HANS & arm/leg straps Test lateral supports for egress - may need foldability
Concept #3		
Raise feet and swing in XZ with knees bent like Soyuz - seat needs to miss ECLSS during swing. (Swing about I/F of struts at head?)	Small Stroke ability for X & Y if required.	Foot & Knee Position like Soyuz (with the ability to stretch legs and strap down shortly before Launch & Landing) Non-foldable lat supports - test for egress
Concept #4		
Air Bag System for contingency landing (land) behind pallet to react in X and Z Direction. Contact ILC Dover to discuss options (Ed Fasinella - LaRC).	Rigid fixed interface of seat to pallet	Standard Seat Design (Gohmert) or NASCAR type bucket seat.
Concept #5	Relaxed Brinkley in X & Y	
Fixed Pallet interface to backbone (If okay for Water, but not Land, develop attenuation system for land impact).	Add Isolation to interface of Seat to Pallet (low frequency) Seat attenuation in Z-axis only, locally at seat interface to pallet.	Foot & Knee Position like Soyuz (with the ability to stretch legs and strap down shortly before Launch & Landing)
Concept #6		
Baseline Strut System Add WireRope or visco-elastic "Bumper" (high frequency) to end-of travel.	With & without isolator to interface of Seat to Pallet (wire rope or other visco elastic isolator system).	Foldable lateral Supports (Y-Axis) Head, Shoulder, Hips

CAD Concept Study Evolution

- Generate CAD layouts using ProE for various configurations
- Evaluated layout geometry
- Evaluated layouts via analyses
- Performed engineering tests to support design
  - Cockpit Working Group Evaluation
  - Seat Belt Tension Concept Evaluation
- Planning engineering tests of load attenuation system to correlate results to mathematical models

Lap belt

Shoulder harness

Analysis Tools

Seat/Pallet Isolation Evaluation 2 DoF System (Excel)

- Simplified models allow rapid evaluation of design parameters
  - Must be sufficiently accurate & verified to achieve intended goals

<u>Simple 2 DoF analysis:</u>

1) Evaluation of CM CG to pallet relative displacements
2) 2DoF systems: LM case 21 Z crew acceleration at pallet location 1 as input to 2DoF system consisting of:

   m1 = m seat = 15 kg

   k1 = k seat/pallet

   m2 = m crew (includes suit) = 136 kg

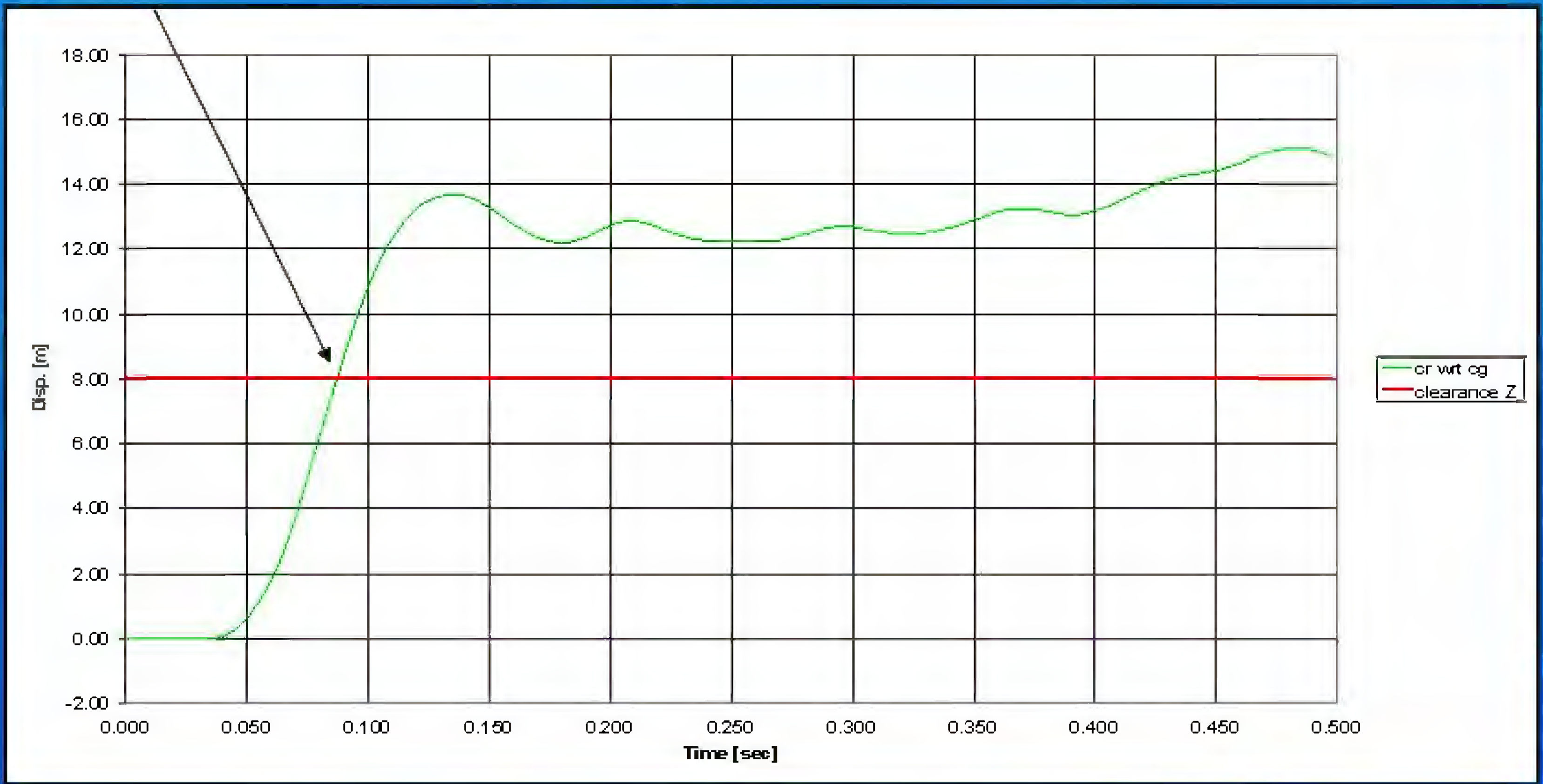
   k2 = k crew, set to get Brinkley fnz = 8.42 Hz (spinal direction)

   Objective: look for candidates k1 such as to attenuate peak acceleration, meet DRI requirement of 13 g with lesser amount of additional stroke. Compute acceleration onset

3) Optimization run for constant spring (SDoF where mass = m seat + m crew & reference stiffness = k1):
   - Optimization: minimize product of peak acceleration * peak relative displacement for maximum amount of additional stroke (design TBD)
   - Compute acceleration onsets [g/s]
   - Optimization variables: initial constant stiffness, initial deflection, past initial deflection is constant spring force (nonlinear spring stiffness)

Seat to Pallet Isolation—Relative Displacement (Excel)

- For case 21 Z evaluated relative displacements (CM-pallet), assuming CM wall is represented by CG displacement & pallet is represented by displacement at crew location 1
  - At 88 msec pallet affects CM (exceeds 8 in clearance)



2 DoF Seat to Pallet Isolation Results Summary (Excel)

Best candidate (2-7-08): Ki=14.5*(f1s*2*pi())^2, Xi=0.02 m

CASE	606C Baseline (Case 21 Z) hard seat (non isolated)	soft seat const. stiff. spring	constant force spring
peak crew accel [m/s2]	177	130	124
DRI [g]	18.1	13.3	12.6
peak rel. disp. [m]	0.06	0.39	0.16
[in]	2.4	15.4	6.3
net [in] (Stroke for seat I/F to Pallet)	0	13.0	4.0
peak crew onset [g/s]	903	226	1806

Exceeds Z DRI (18.1)

Meet Z DRI (13.3, 12.6)

Stroke cost (13.0, 4.0)

Exceeds onset (903)

Meet onset (226)

Exceeds onset (1806)

NASTRAN FE Model of Pallet System

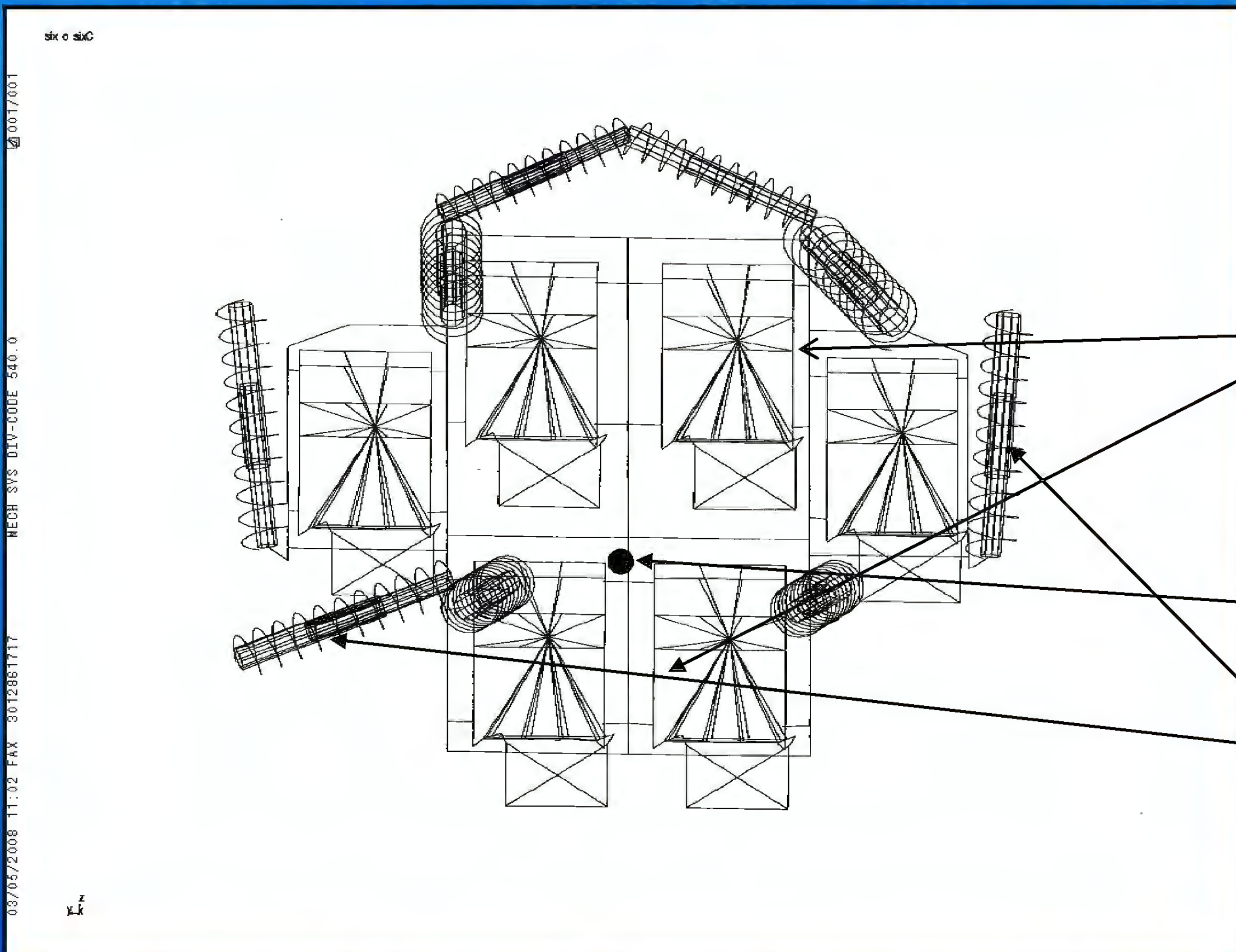
- Insert flexibility of pallet into reduced model
  - Flexibility is required to achieve representative dynamic response

- Pallet model received with 9 struts only 8 attached. F1 reported to be 15 Hz (8 strut model is at 15 Hz)

- 9^{th} strut attached & F1 moved to 19 Hz

ADAMS Kinematic Analyses Model

- Reduced model can be used to perform parametric studies rapidly
- Translated flexible model of pallet into ADAMS code

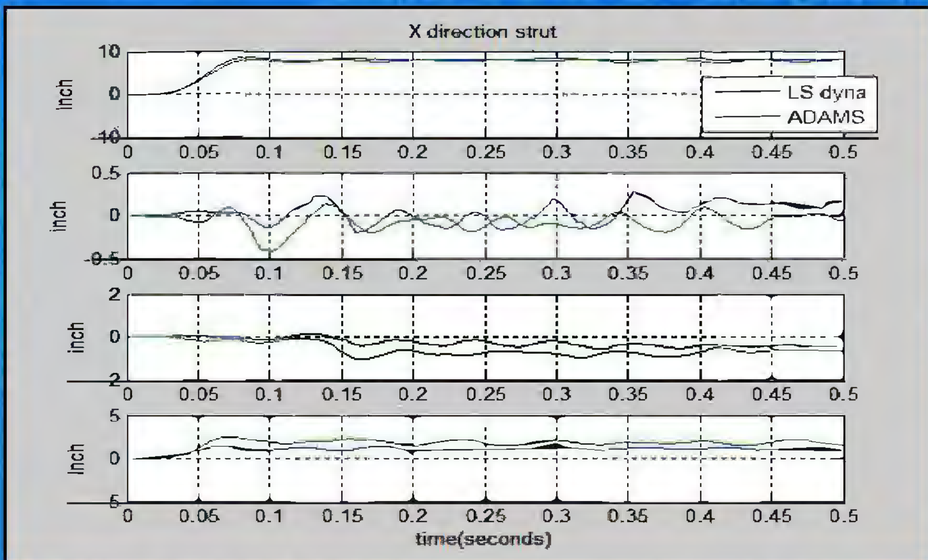


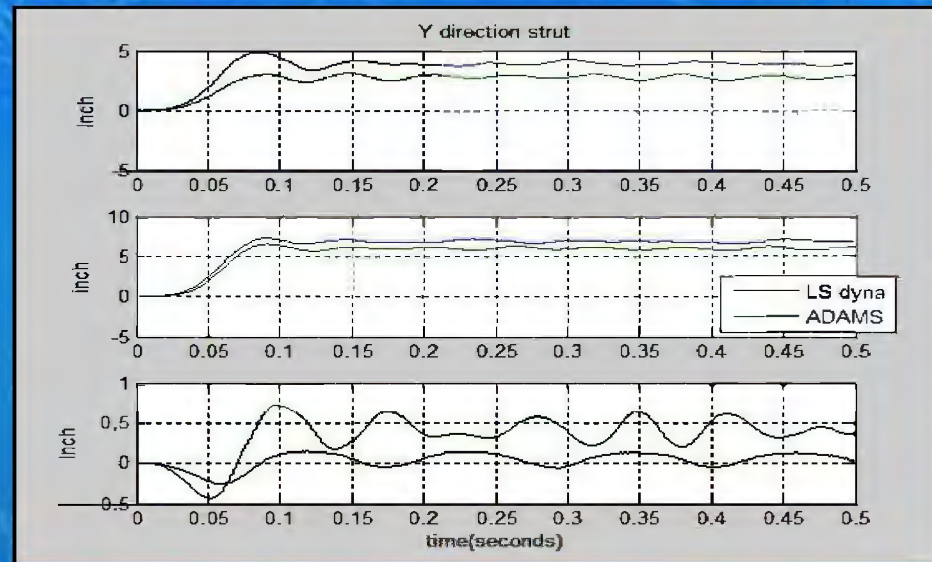
Full [M], [K] & [ϕ] representation of pallet FEM

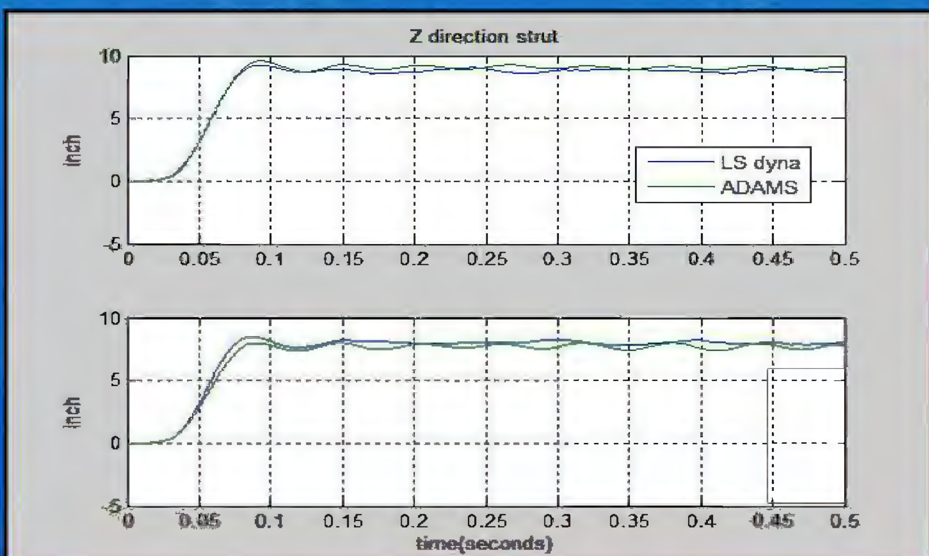
CM point, rigid body application of CM accels

Strut models (linear spring dampers in this case)

ADAMS/Full LS-Dyna Comparison Strut Displacement Comparisons



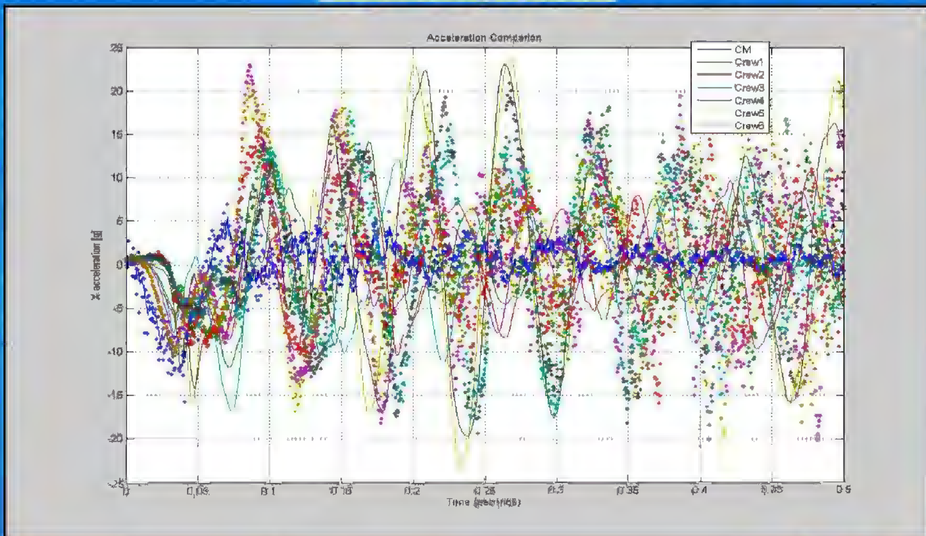




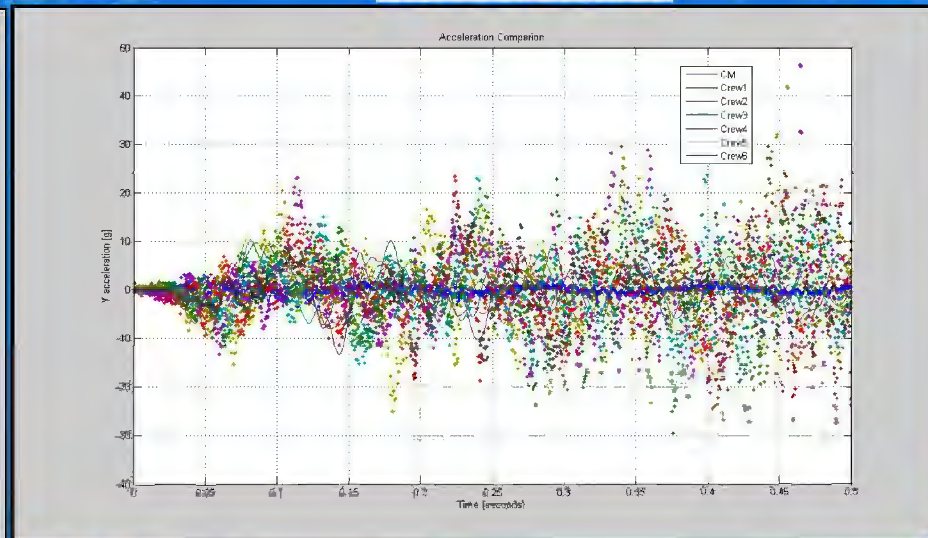
- Case 44384 has been used to compare results between ADAMS & LS-Dyna
- Results of strut displacements match well between Full LS-Dyna & ADAMS

ADAMS/Full LS-Dyna Comparison Acceleration

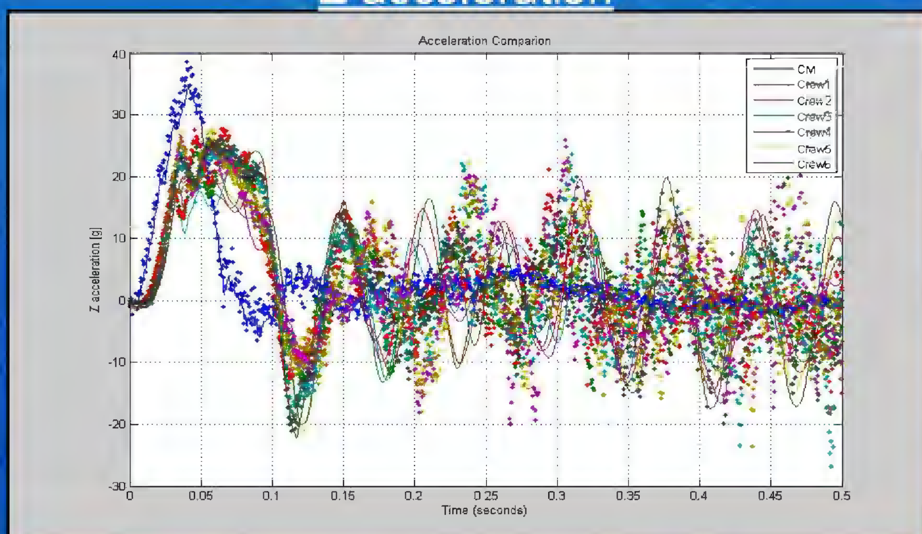
X acceleration



Y acceleration



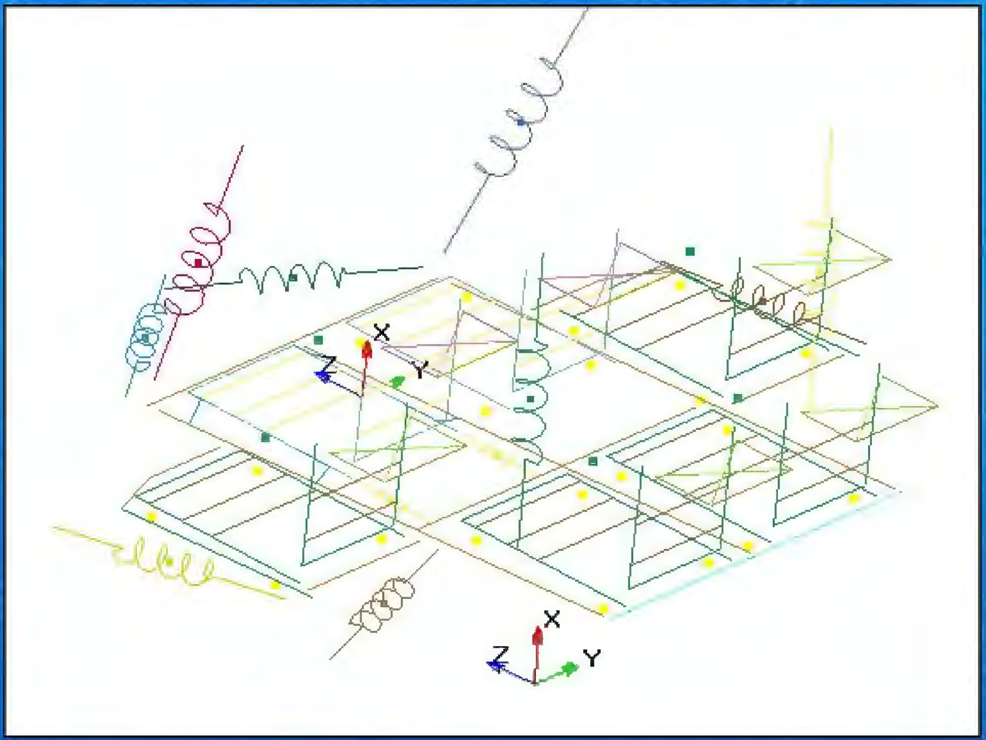
Z acceleration



Points—LS-Dyna
Solid Lines—ADAMS

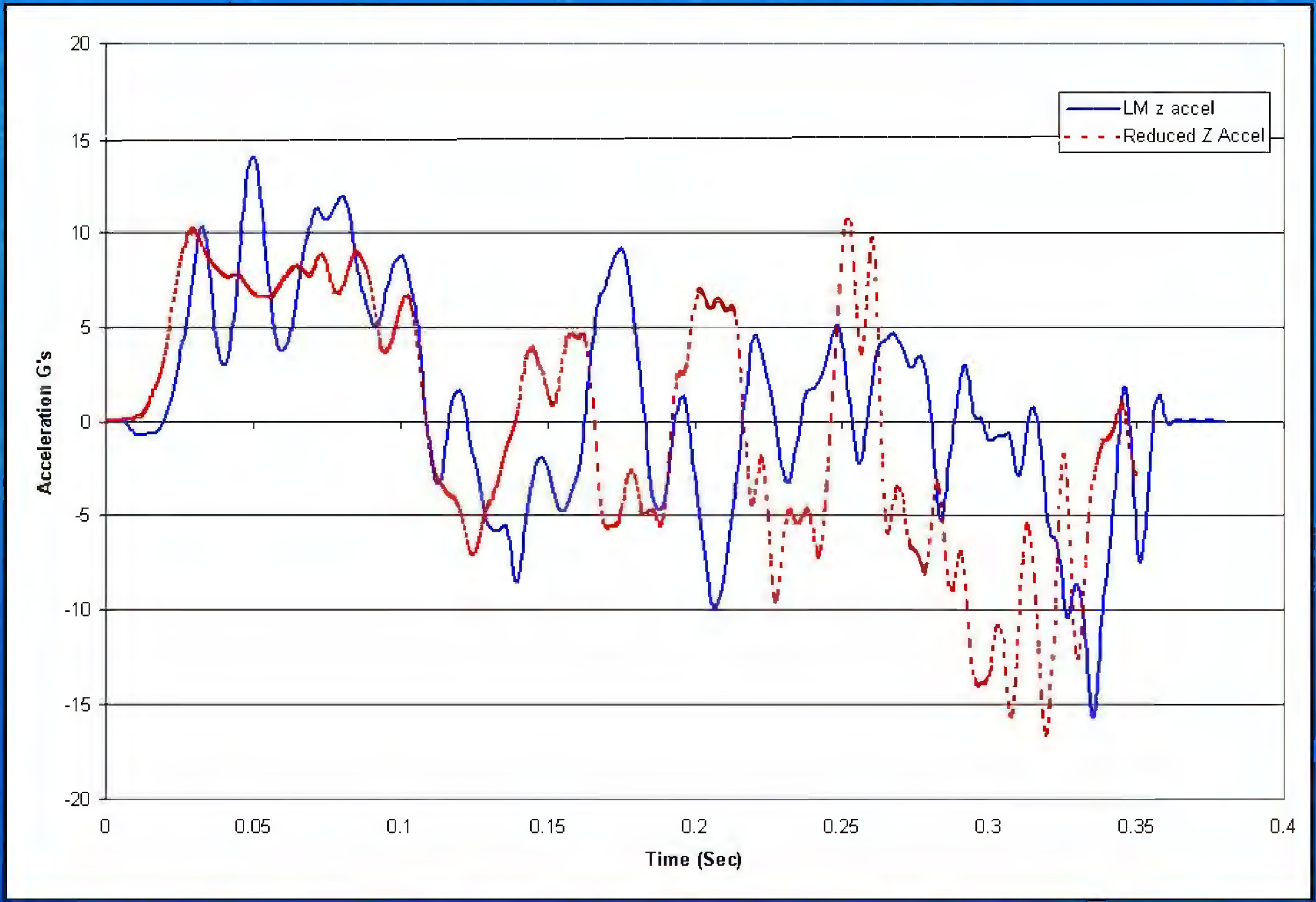
LS-Dyna Reduced Orion Model

- Reduced model generated for performing fast-running simulations
  - LM full model—2 days
    Reduced model—4 minutes
- Created by extracting pallet, seats & pallet struts from full 606B model & rigidly connecting struts to Crew Module cg
- Requires acceleration profiles at cg for assessment load cases from full Orion model to correctly simulate seat pallet behavior
- Models produce close enough results to evaluate effectiveness of concepts



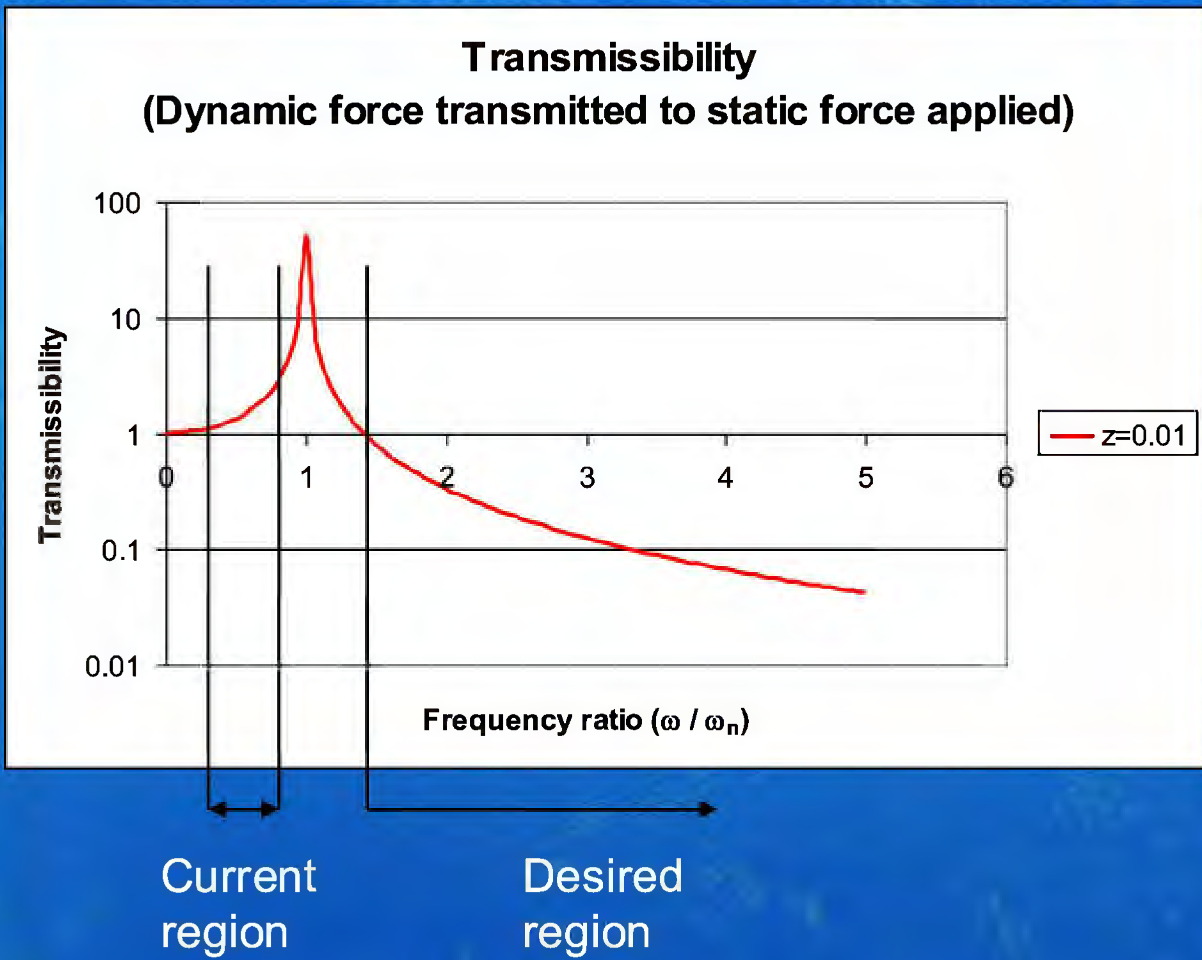
Comparison Between Reduced & LM Full Orion Model

Seat A—Case 15 Z Acceleration
(Accelerations at node 4000407)



Load Isolation Studies

Load Transmissibility Effects

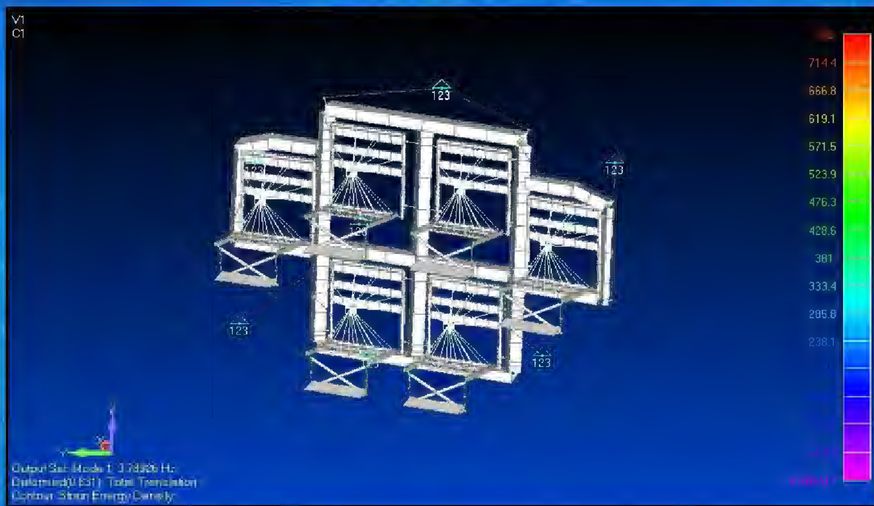


- ω = Input frequency content
- ω_n = Pallet system frequency
- If pallet system frequency is greater than that of input, transmissibility will never be < 1
- By dropping pallet system frequency below that of input, transmissibility can be < 1: ISOLATION

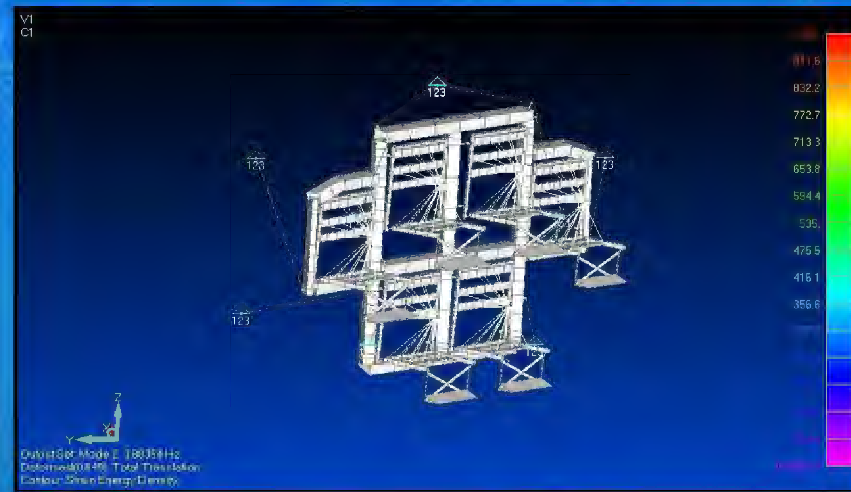
ADAMS Isolation Model Comparison & Brinkley Results

- To explore potential benefits of isolation system on crew loads, baseline coulomb friction struts were replaced with spring dampers with stiffness & damping coefficient of 1,000 lb/in. & 20 lb-s/in., respectively
- Other than struts, isolation model is same as baseline; 9-strut configuration with CEV CM location consistent with 606B design

1,000 lb/in. Isolation Struts



F1 = 3.8 Hz



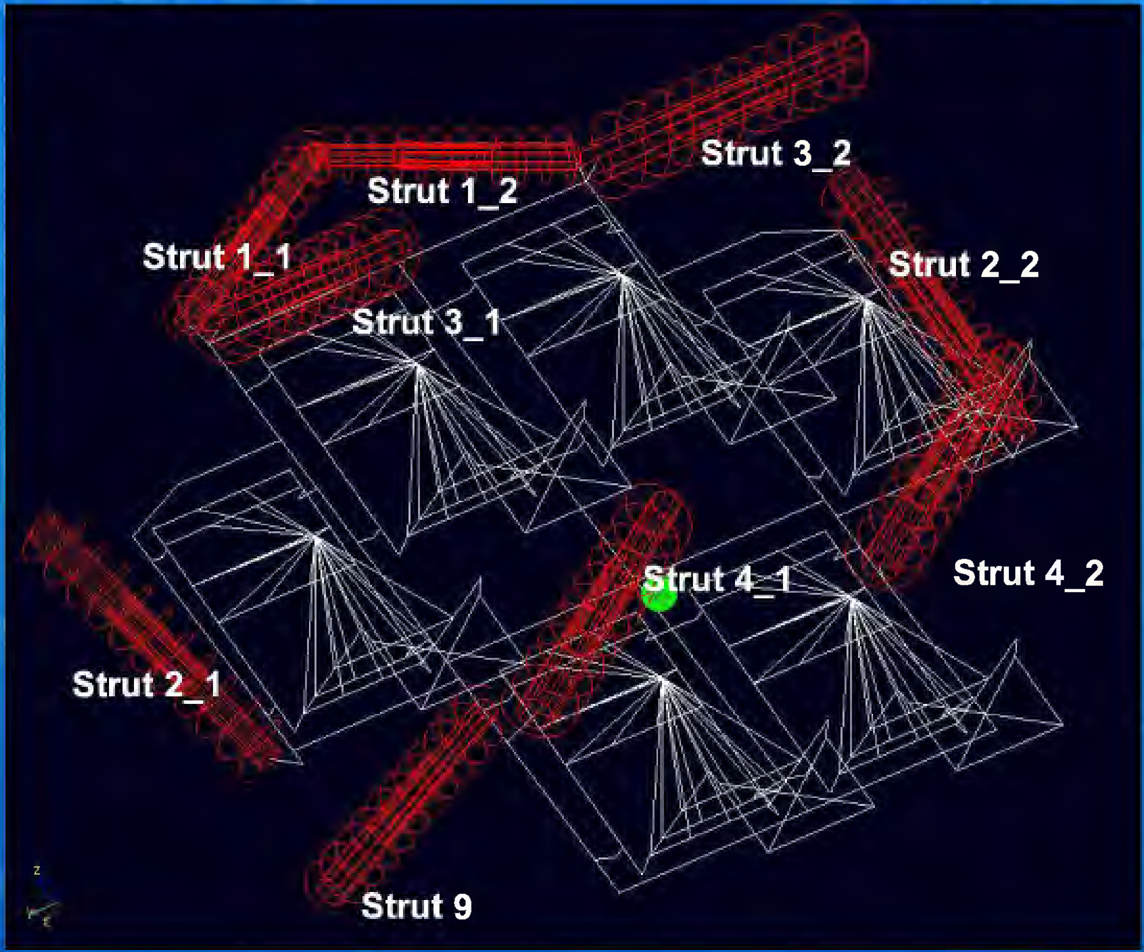
F2 = 3.9 Hz

F3 = 5.1 Hz

- Softened struts move fundamental modes below excitation frequencies
- System acts as low pass filter. Pallet moves as rigid body

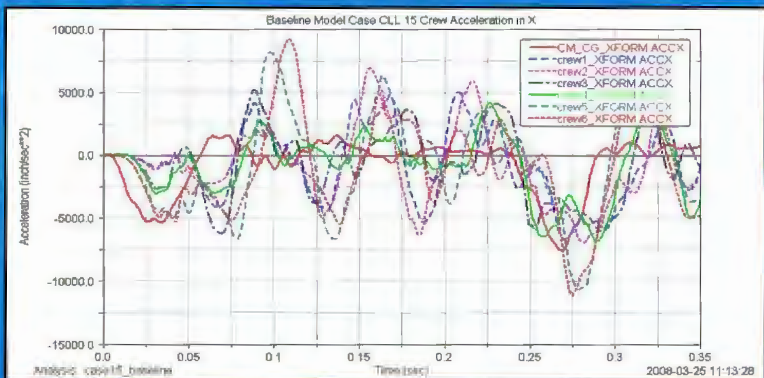
ADAMS Isolation Model

- Coordinate System:
  - X direction – frontal impact
  - Y direction – side impact
  - Z direction – spinal impact
- Strut direction
  - 1_1 & 1_2 = Y & Z direction
  - 2_1 & 2_2 = Z direction
  - 3_1 & 3_2 = X direction
  - 4_1 & 4_2 = X direction
  - 9 = Y direction

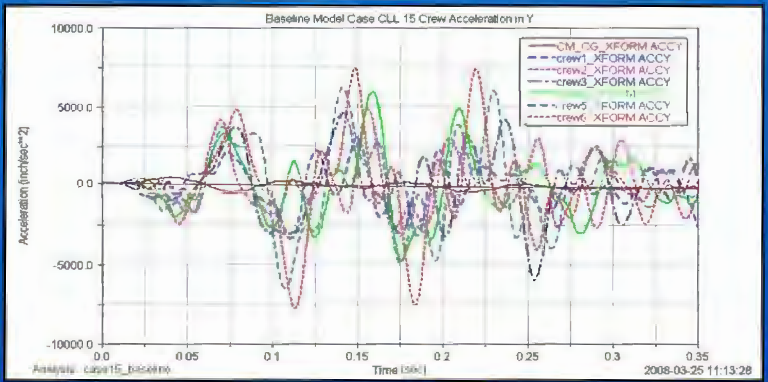


Comparison of Baseline 606 & Isolated (Reduced Model): CLL Case 15

Baseline model results

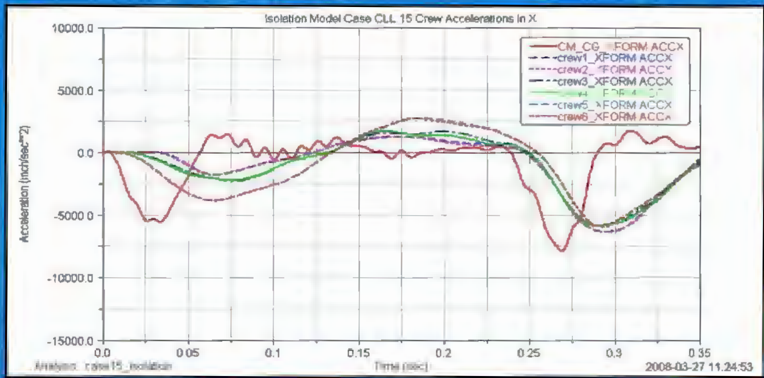


Max crew X acceleration (frontal impact) = 11,123 in./s² or 28.8 G

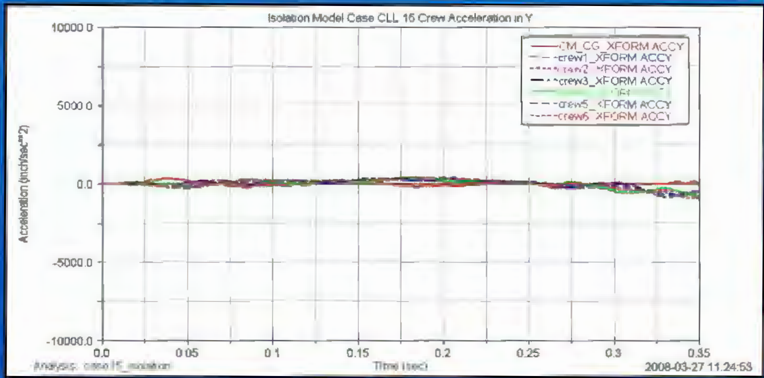


Max crew Y acceleration (side impact) = 7,741 in./s² or 20 G

Isolation model results



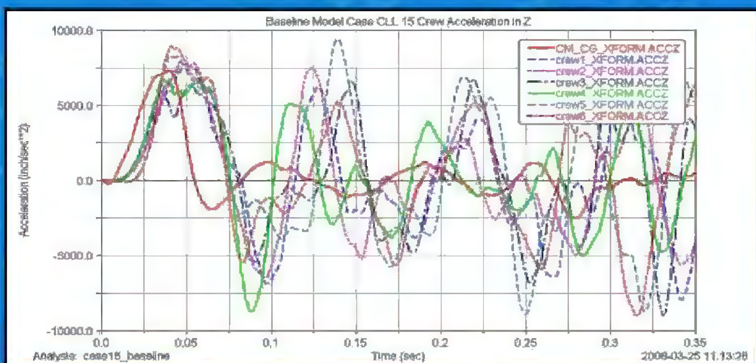
Max crew X acceleration (frontal impact) = 6,316 in./s² or 16.36 G



Max crew Y acceleration (side impact) = 907 in./s² or 2.3 G

Comparison of Baseline 606 & Isolated (Reduced Model): CLL Case 15 (cont.)

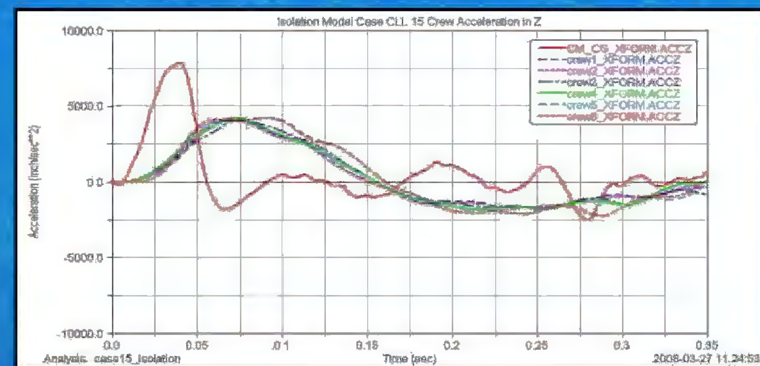
Baseline model results



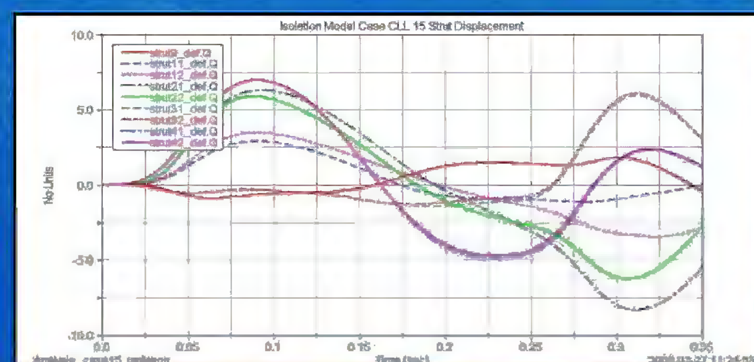
Max crew Z acceleration (frontal impact) = 9,454 in./s² or 24.5 G

Max strut displacement = 5.96 in.

Isolation model results



Max crew Z acceleration (frontal impact) = 4,244 in./s² or 11 G



Max strut displacement = 8.33 in.

Conclusions: Isolation vs. Baseline

- Baseline model with friction struts actually amplifies CG loads onto crew. There is attenuation when CG accelerations are very high; otherwise all loads are amplified, not attenuated. Thus, crew loads would be reduced in most cases if crew was rigidly attached to CEV CG
- Isolation (only) model shows great promise in reducing dynamic loading of crew accelerations. Isolation model strokes more than baseline model but remains under allowable 8 in. for most cases except CLL 21 & 23. More work required to meet all cases
- Values of k & c for isolation struts must be optimized to stay within allowable stroke limits
- Potential design solution using both attenuation & isolation
  - Attenuation (stroke) used for absorption of impact energy to lower acceleration
  - Isolation (low frequency) used to reduce dynamic amplification from Orion structure to crew

Brinkley Model Results Case CLL 15 (Input from ADAMS Reduced Model)

- Brinkley model crew accelerations were used to obtain more accurate Brinkley injury criteria results

Comparison Between Baseline and Isolation Models' Response to CLL Case 15				
	X Axis Risk	Y Axis Risk	Z Axis Risk	High Risk Injury Criteria (>1 shows high risk)
Baseline Model				
Crewman 1	Low	Very Low	High	0.93
Crewman 2	Low	Very Low	High	0.89
Crewman 3	Moderate	Very Low	High	1.07
Crewman 4	Moderate	Very Low	High	1.03
Crewman 5	Moderate	Very Low	High	0.93
Crewman 6	Low	Very Low	High	0.84
Isolation Model				
Crewman 1	Low	Very Low	Very Low	0.58
Crewman 2	Low	Very Low	Very Low	0.58
Crewman 3	Low	Very Low	Low	0.69
Crewman 4	Low	Very Low	Low	0.68
Crewman 5	Low	Very Low	Very Low	0.59
Crewman 6	Low	Very Low	Very Low	0.57

Problem Summary

Problem Summary

- System goal:
  - Develop best occupant protection system possible for Orion that maximizes crew safety during ascent, ascent aborts (if required), landing (water nominal with land landing contingency) & post-landing recovery
- Innovative engineering is required to solve this complex system problem
- Tools used for this challenge include:
  - Basic math modeling tools such as Excel & hand calculations
  - Computer aided design (CAD) such as ProE or SolidWorks
  - Finite element analyses (FEA) such as NASTRAN, ADAMS, LS-Dyna
  - Unique analysis tools such as Brinkley (Crew Injury Probability) software
- Problem considerations include:
  - "Out of box" thinking
  - Explore wide range of options & evaluate through analyses & engineering data
  - Design concepts should include hardware that is readily available
  - Understand system perspective & effect on other systems

Lesson 7: Orion Landing Attenuation

Design Challenge

Joe Pellicciotti

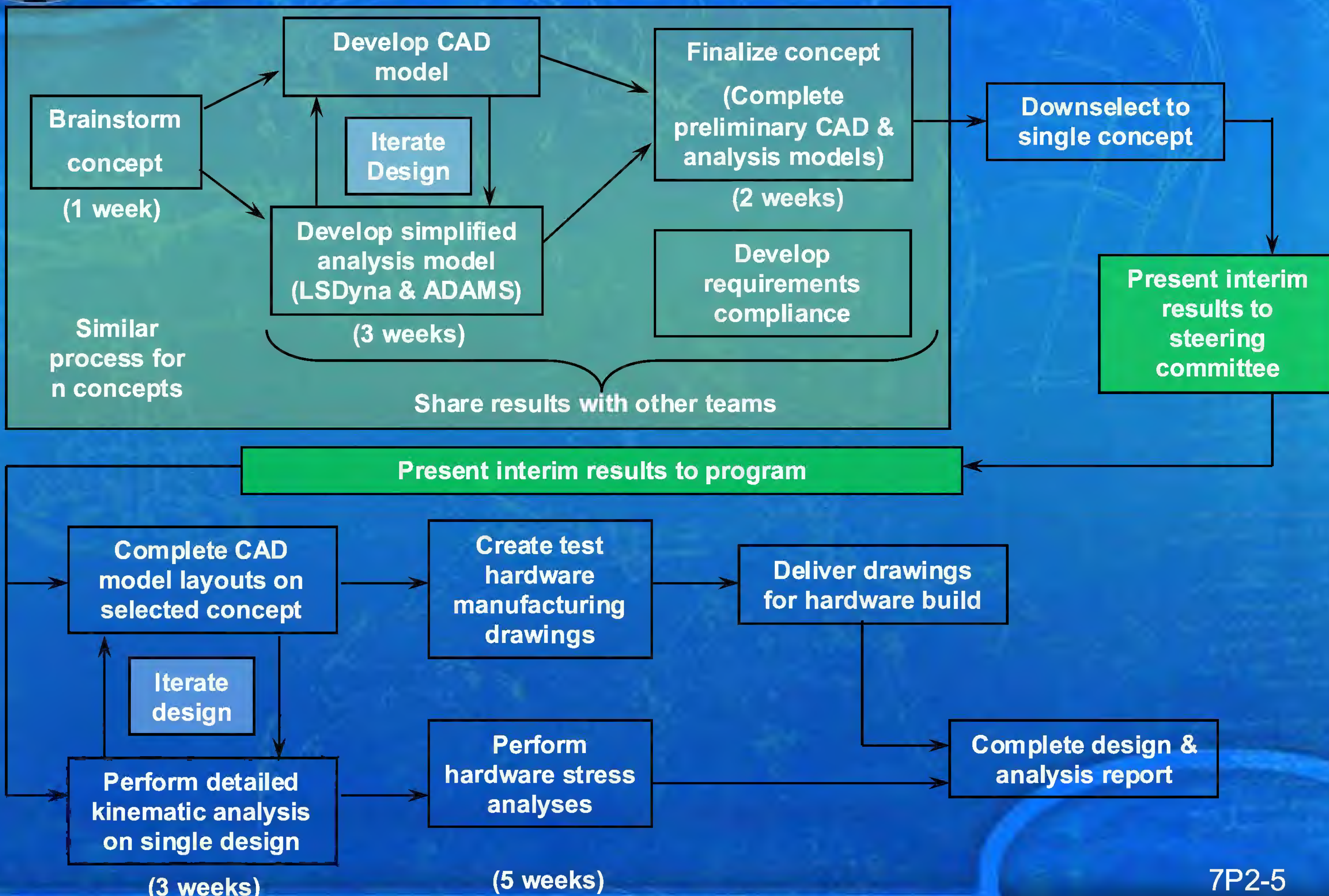
Analysis Tools

Design & Analysis Tools Used by NASA Team

- Design
  - Computer aided design (CAD)
    - ProEngineer used for all modeling & configuration management (Windchill Project Link)
  - Engineering tests
- Analyses
  - Excel
    - Simplified 2-DoF analyses
  - NASTRAN
    - Flexible body input
    - Hardware strength sizing
    - Frequency analysis
  - ADAMS
    - Reduced kinematic models
    - Full model system verification
  - LSDyna
    - Reduced kinematic models
    - Full model system verification
  - Brinkley model
    - Determine susceptibility to crew injury based on crew member acceleration

System Design Studies

NESC Team Operation Flow



What issues do you see with the NESC Team Operation Flow?

0% a. Concept development phase is not sufficiently focused
0% b. Concept development phase is too long
0% c. Concept development phase is too short
0% d. Requirement interaction is not sufficiently defined
0% e. Project Manager input is not frequent enough
0% f. Other (be prepared to discuss)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

Answer Now

10

Design Concept Definition Matrix

Investigated slight variation of these concepts based on continued information flow (design, analysis & test data from previous efforts)

Combined into primary design (Concepts #1–#2)

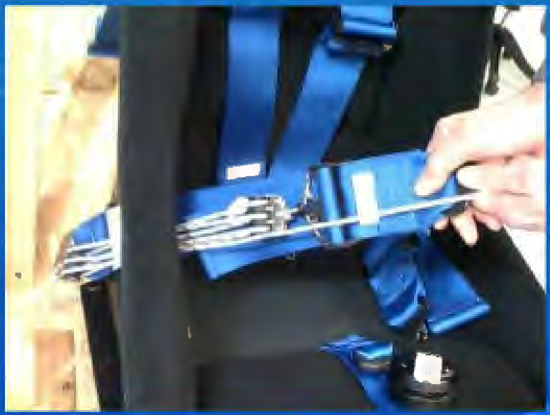
Promising but lowest priority for investigation due to resource limitations (Concept #4)

Struts and Inteface to Pallet	Pallet & Interface to Seat	Seat & Interface to Crew
Concept #1		
Fix Pallet interface to backbone in X& Y, slip mechanism for Z motion.	Rigid fixed interface of seat to pallet	Foot & Knee Position like Soyuz (with the ability to stretch legs and strap down shortly before Launch & Landing)
Concept #2		
Raise head of pallet and and swing in X/Z (Pivot at Crew feet) - possibly use a rotary attenuation system.	Small Stroke ability for X& Y if required.	NASCAR-Type bucket seat with adjustable foot plate and back length. (i.e. adjust shoulder/head support - PR); HANS & arm/leg straps Test lateral supports for egress - may need foldability
Concept #3		
Raise feet and swing in X/Z with knees bent like Soyuz - seat needs to miss ECLSS during swing. (Swing about I/F of struts at head?)	Small Stroke ability for X& Y if required.	Foot & Knee Position like Soyuz (with the ability to stretch legs and strap down shortly before Launch & Landing) Non-foldable lat supports - test for egress
Concept #4		
Air Bag System for contingency landing (land) behind pallet to react in X and Z Direction. Contact ILC Dover to discuss options (Ed Fasinella - LaRC).	Rigid fixed interface of seat to pallet	Standard Seat Design (Gohmert) or NASCAR type bucket seat.
Concept #5	Relaxed Brinkley in X& Y	
Fixed Pallet interface to backbone (If okay for Water, but not Land, develop attenuation system for land impact).	Add Isolation to interface of Seat to Pallet (low frequency) Seat attenuation in Z-axis only, locally at seat interface to pallet.	Foot & Knee Position like Soyuz (with the ability to stretch legs and strap down shortly before Launch & Landing)
Concept #6		
Baseline Strut System Add WireRope or visco-elastic "Bumper" (high frequency) to end-of travel.	With & without isolator to interface of Seat to Pallet (wire rope or other visco elastic isolator system).	Foldable lateral Supports (Y-Axis) Head, Shoulder, Hips

CAD Concept Study Evolution

- Generate CAD layouts using ProE for various configurations
- Evaluated layout geometry
- Evaluated layouts via analyses
- Performed engineering tests to support design
  - Cockpit Working Group Evaluation
  - Seat Belt Tension Concept Evaluation
- Planning engineering tests of load attenuation system to correlate results to mathematical models

Lap belt



Shoulder harness

Analysis Tools

Seat/Pallet Isolation Evaluation 2 DoF System (Excel)

- Simplified models allow rapid evaluation of design parameters
  - Must be sufficiently accurate & verified to achieve intended goals

Simple 2 DoF analysis:

1) Evaluation of CM CG to pallet relative displacements
2) 2DoF systems: LM case 21 Z crew acceleration at pallet location 1 as input to 2DoF system consisting of:

   m1 = m seat = 15 kg

   k1 = k seat/pallet

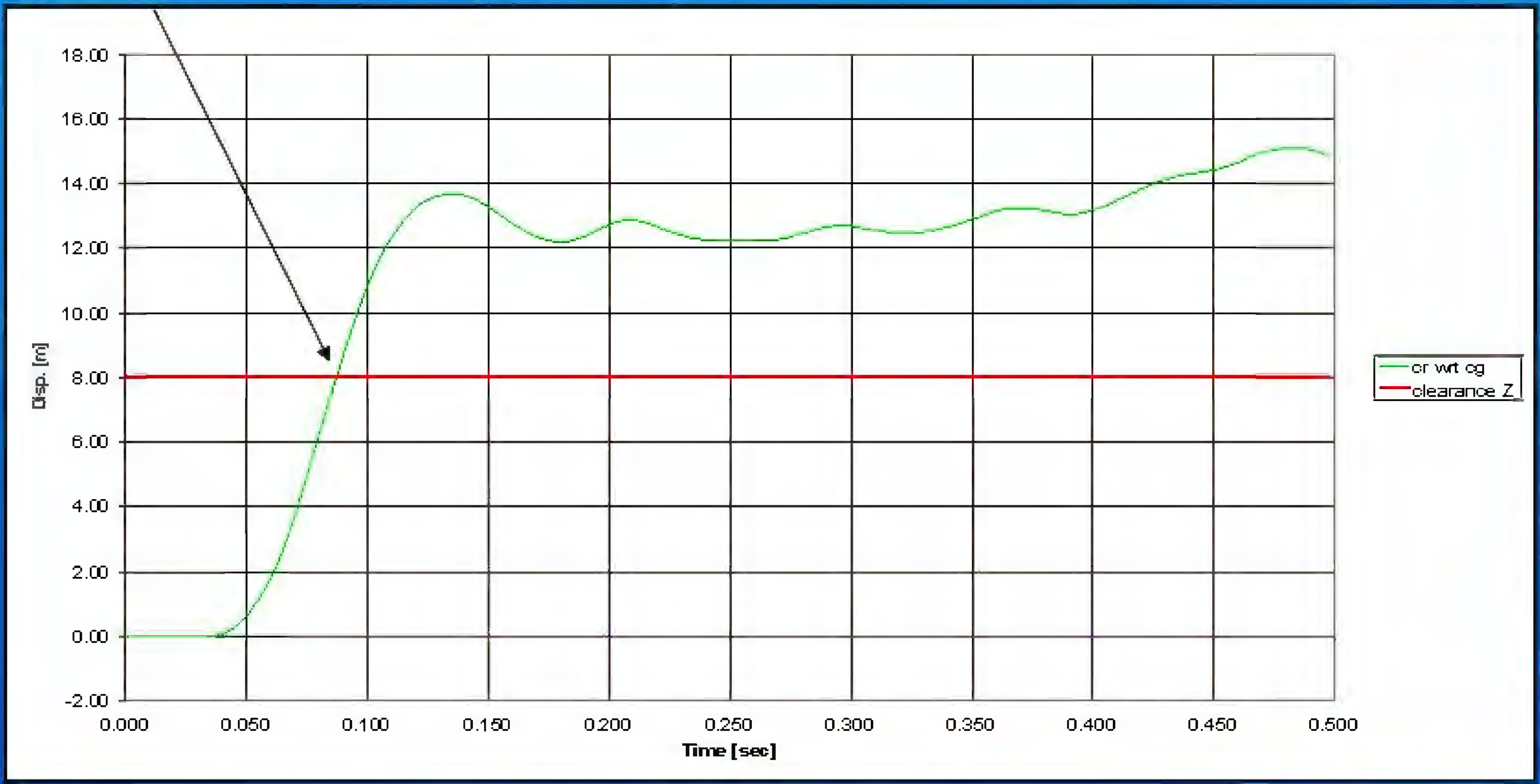
   m2 = m crew (includes suit) = 136 kg

   k2 = k crew, set to get Brinkley fnz = 8.42 Hz (spinal direction)

   Objective: look for candidates k1 such as to attenuate peak acceleration, meet DRI requirement of 13 g with lesser amount of additional stroke. Compute acceleration onset
3) Optimization run for constant spring (SDoF where mass = m seat + m crew & reference stiffness = k1):
   - Optimization: minimize product of peak acceleration * peak relative displacement for maximum amount of additional stroke (design TBD)
   - Compute acceleration onsets [g/s]
   - Optimization variables: initial constant stiffness, initial deflection, past initial deflection is constant spring force (nonlinear spring stiffness)

Seat to Pallet Isolation—Relative Displacement (Excel)

- For case 21 Z evaluated relative displacements (CM-pallet), assuming CM wall is represented by CG displacement & pallet is represented by displacement at crew location 1
  - At 88 msec pallet affects CM (exceeds 8 in clearance)



2 DoF Seat to Pallet Isolation Results Summary (Excel)

Best candidate (2-7-08): Ki=14.5*(f1s*2*pi())^2, Xi=0.02 m

606C Baseline (Case 21 Z)

CASE	hard seat (non isolated)	soft seat const.stiff. spring	constant force spring
peak crew accel [m/s2]	177	130	124
DRI [g]	18.1	13.3	12.6
peak rel. disp. [m]	0.06	0.39	0.16
[in]	2.4	15.4	6.3
net [in] (Stroke for seat I/F to Pallet)	0	13.0	4.0
peak crew onset [g/s]	903	226	1806

Exceeds Z DRI (hard seat DRI 18.1)

Meet Z DRI (13.3, 12.6)

Stroke cost (13.0, 4.0)

Exceeds onset (903) | Meet onset (226) | Exceeds onset (1806)

NASTRAN FE Model of Pallet System

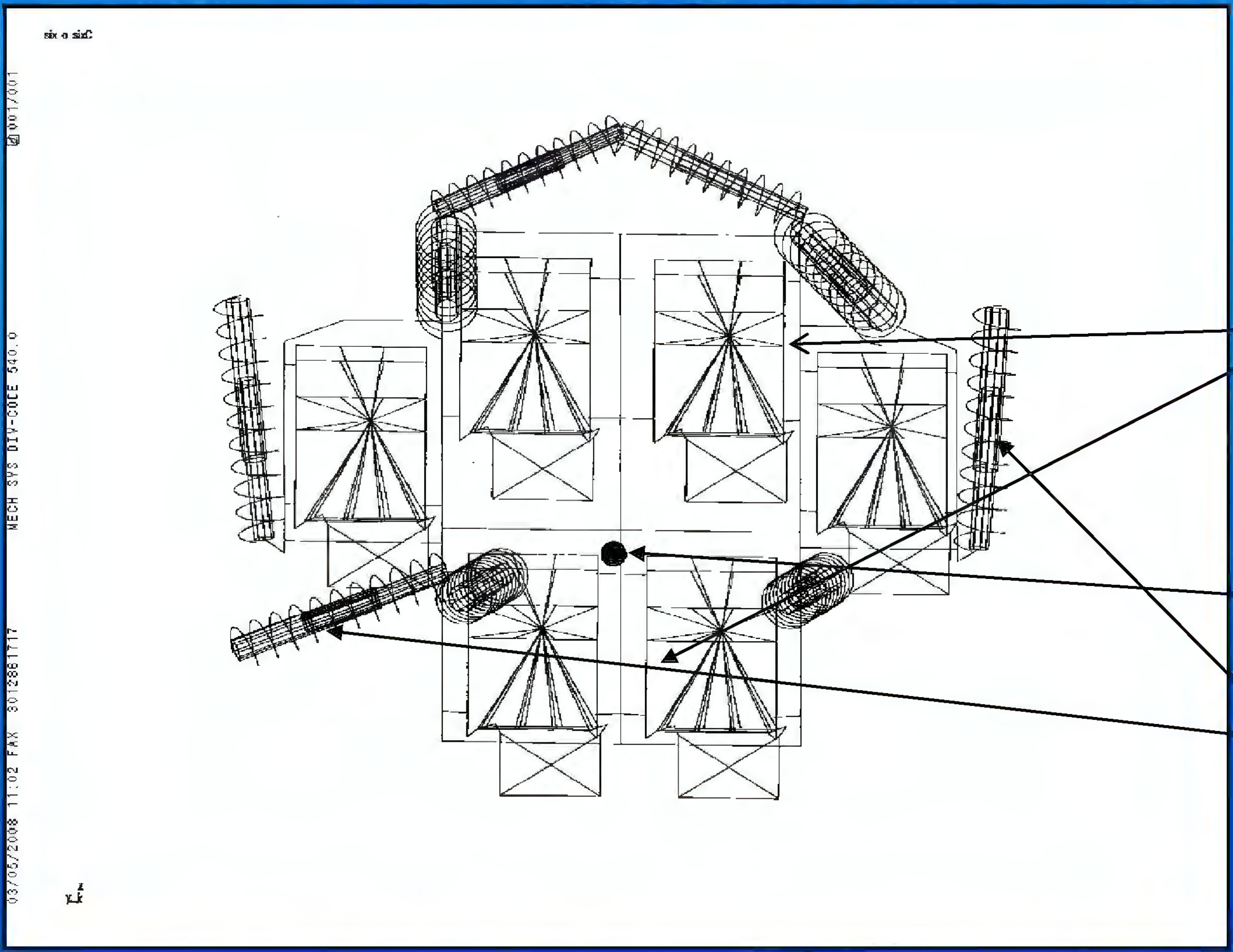
- Insert flexibility of pallet into reduced model
  - Flexibility is required to achieve representative dynamic response

- Pallet model received with 9 struts only 8 attached. F1 reported to be 15 Hz (8 strut model is at 15 Hz)

- 9th strut attached & F1 moved to 19 Hz

ADAMS Kinematic Analyses Model

- Reduced model can be used to perform parametric studies rapidly
- Translated flexible model of pallet into ADAMS code

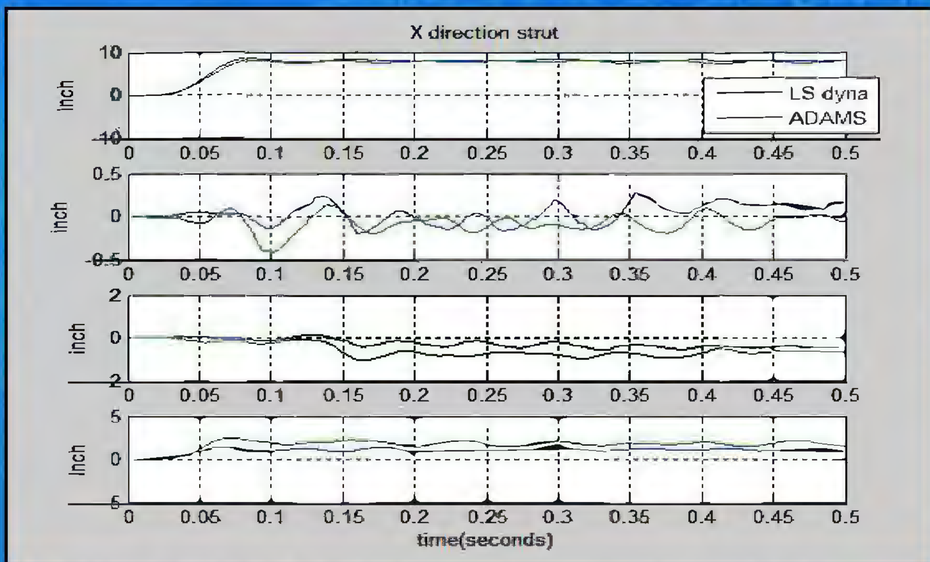


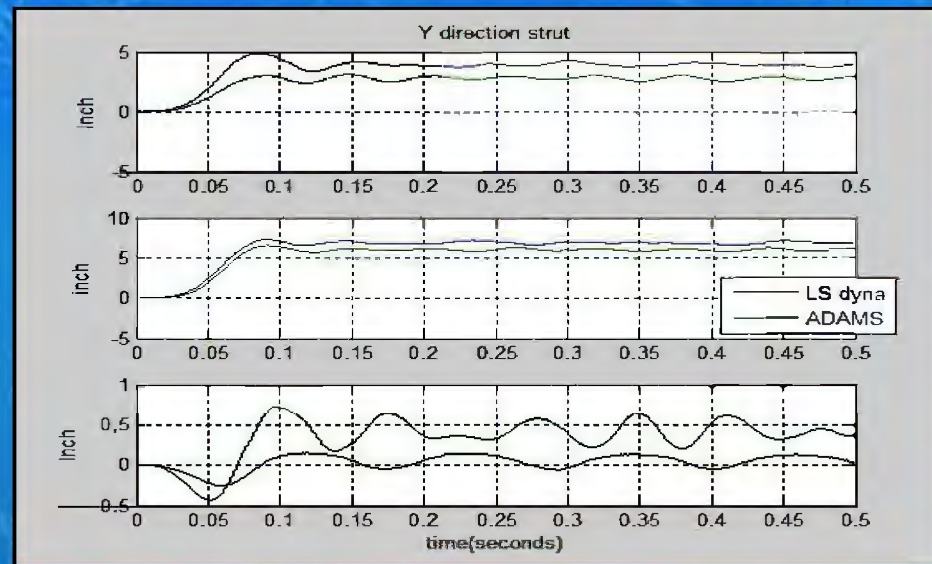
Full [M], [K] & [ϕ] representation of pallet FEM

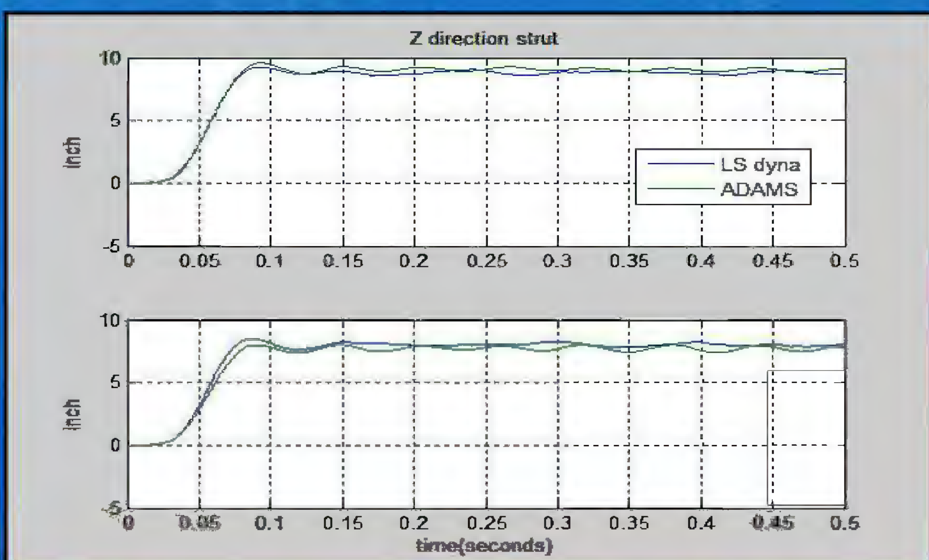
CM point, rigid body application of CM accels

Strut models (linear spring dampers in this case)

ADAMS/Full LS-Dyna Comparison Strut Displacement Comparisons



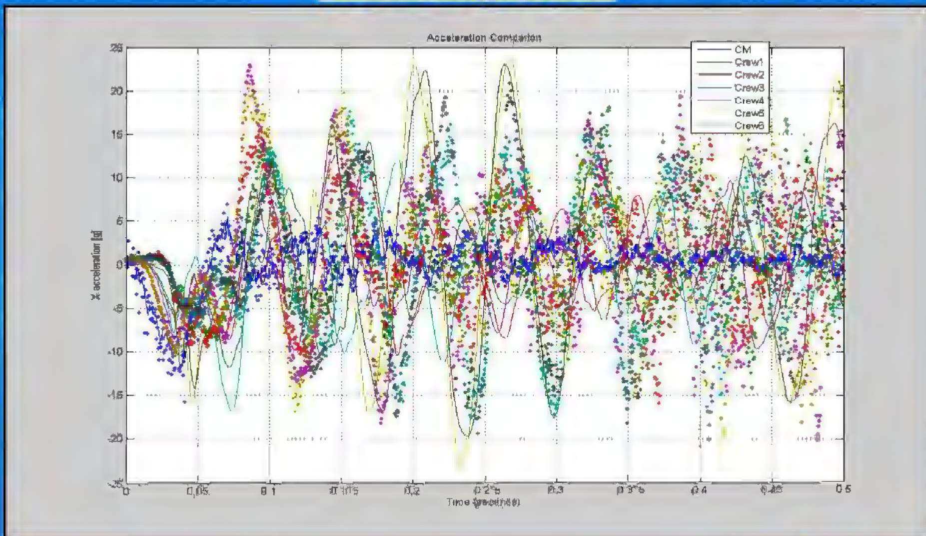




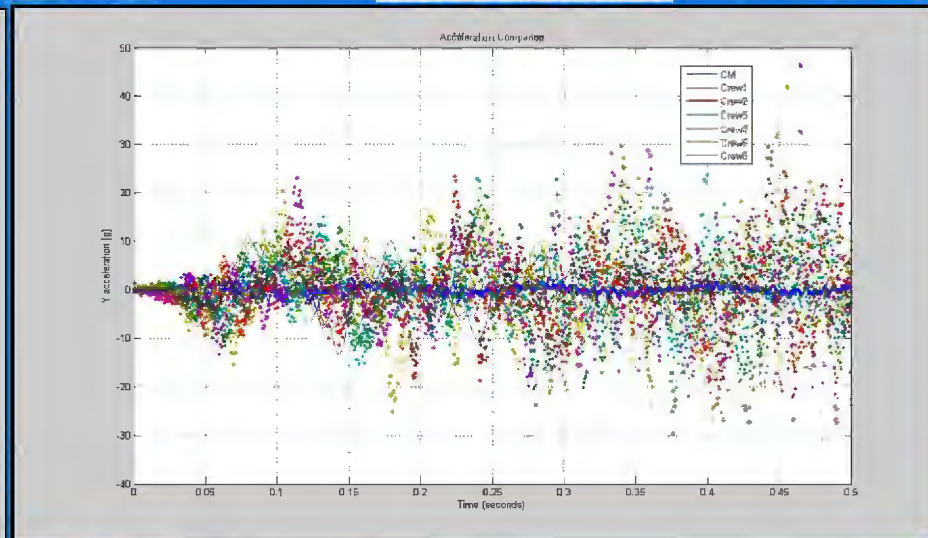
- Case 44384 has been used to compare results between ADAMS & LS-Dyna
- Results of strut displacements match well between Full LS-Dyna & ADAMS

ADAMS/Full LS-Dyna Comparison Acceleration

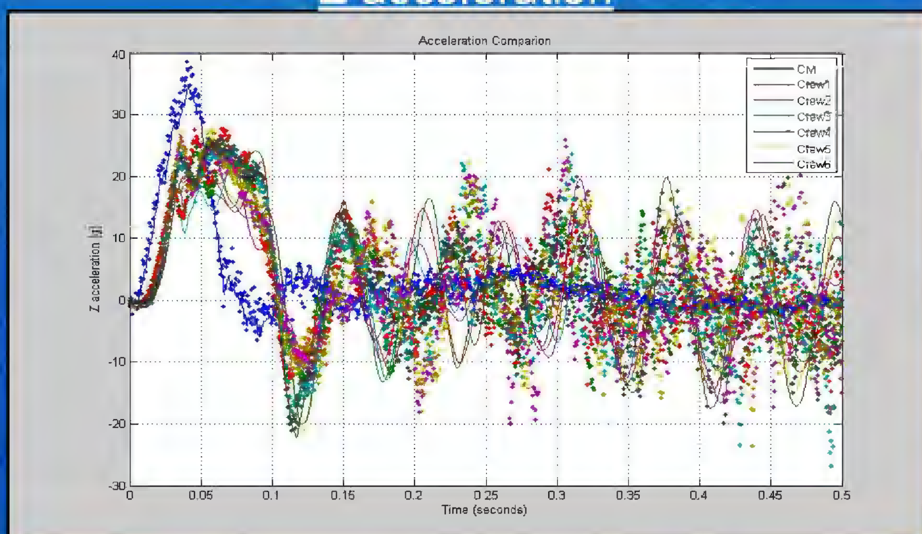
X acceleration



Y acceleration



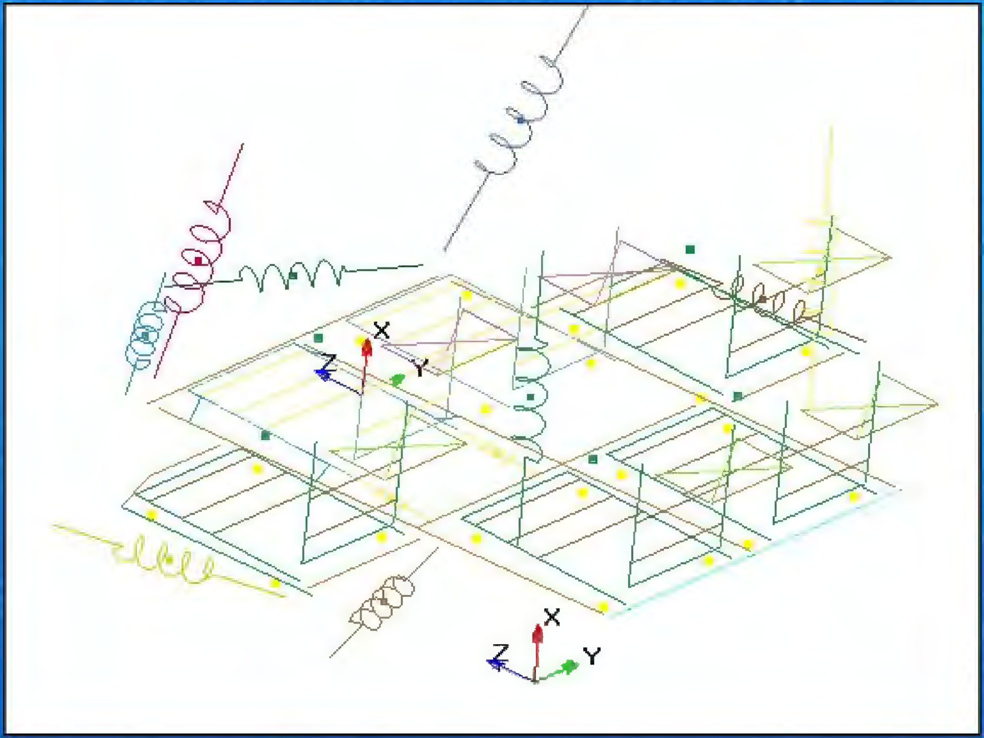
Z acceleration



Points—LS-Dyna
Solid Lines—ADAMS

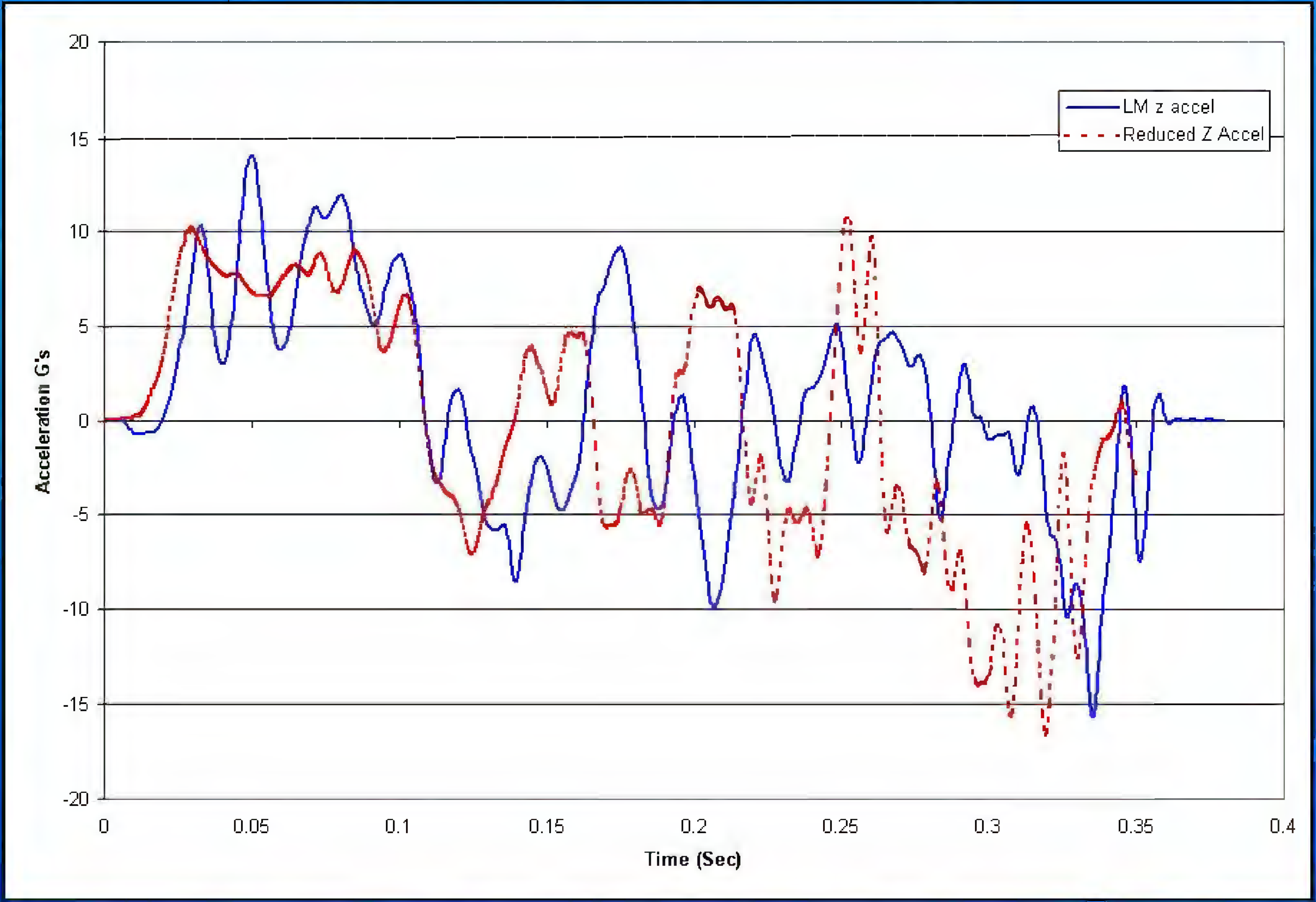
LS-Dyna Reduced Orion Model

- Reduced model generated for performing fast-running simulations
  - LM full model—2 days Reduced model—4 minutes
- Created by extracting pallet, seats & pallet struts from full 606B model & rigidly connecting struts to Crew Module cg
- Requires acceleration profiles at cg for assessment load cases from full Orion model to correctly simulate seat pallet behavior
- Models produce close enough results to evaluate effectiveness of concepts



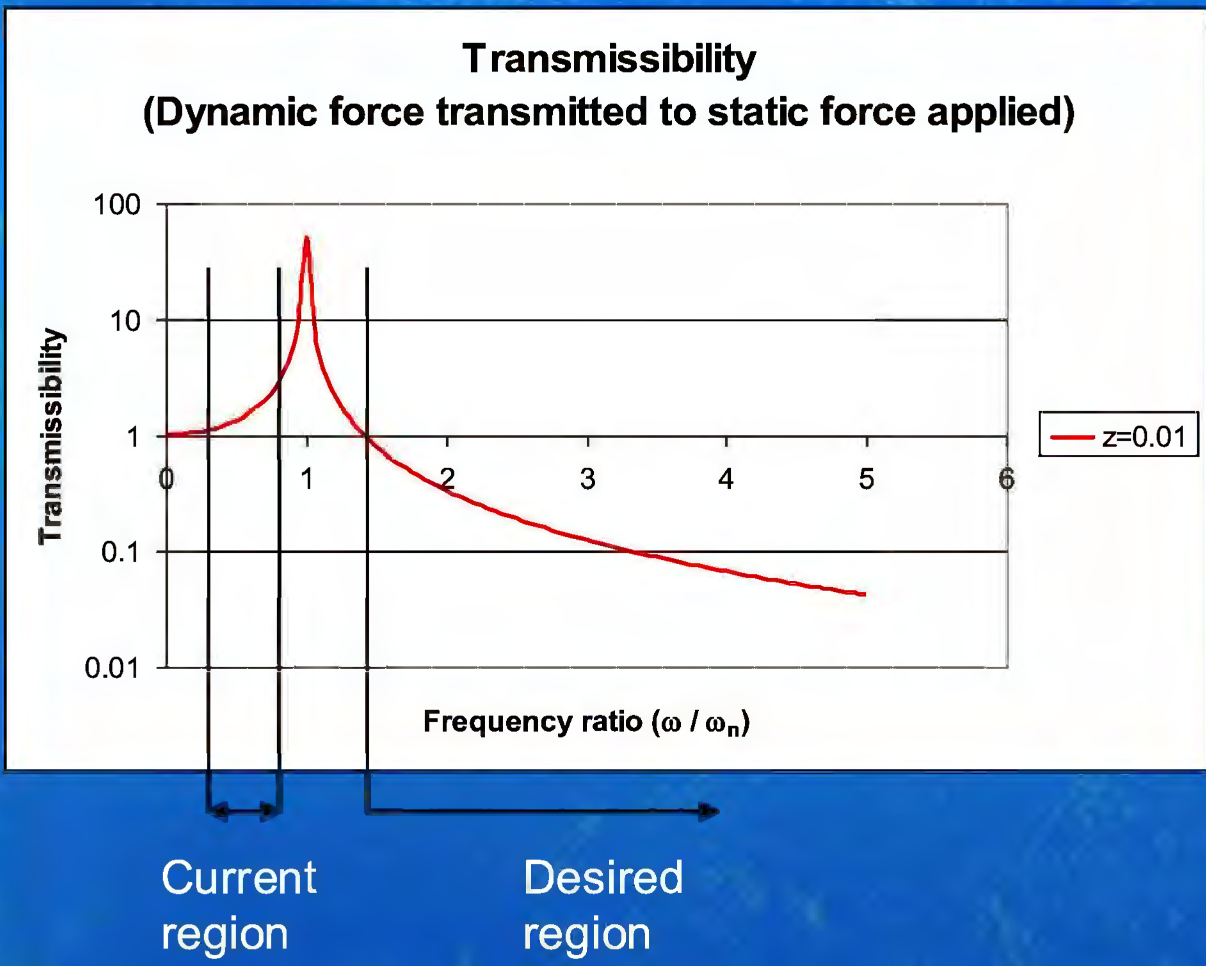
Comparison Between Reduced & LM Full Orion Model

Seat A—Case 15 Z Acceleration
(Accelerations at node 4000407)



Load Isolation Studies

Load Transmissibility Effects

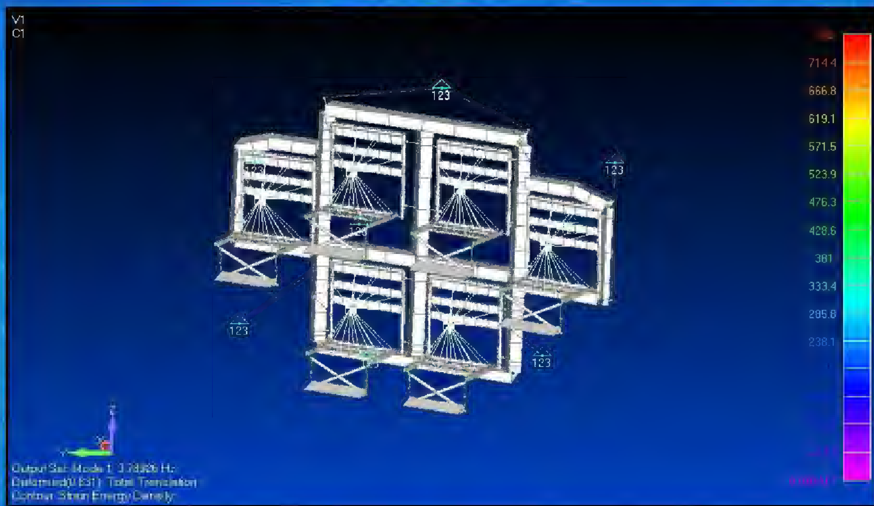


- ω = Input frequency content
- ω_n = Pallet system frequency
- If pallet system frequency is greater than that of input, transmissibility will never be < 1
- By dropping pallet system frequency below that of input, transmissibility can be < 1: ISOLATION

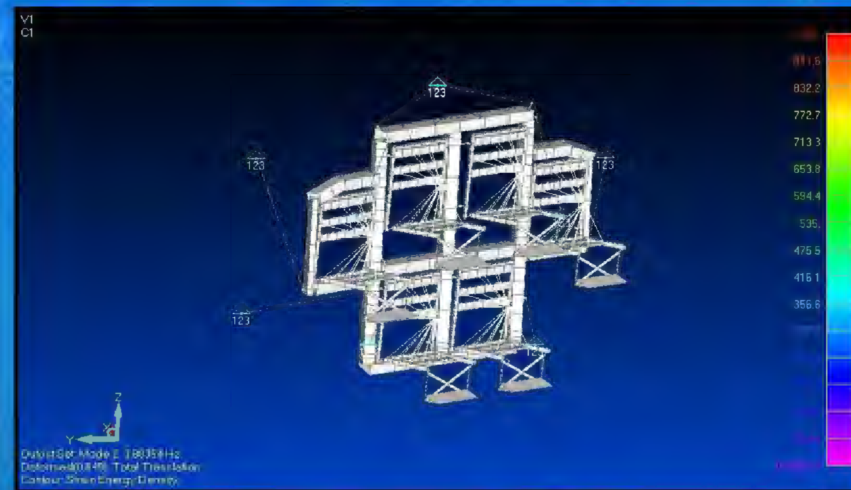
ADAMS Isolation Model Comparison & Brinkley Results

- To explore potential benefits of isolation system on crew loads, baseline coulomb friction struts were replaced with spring dampers with stiffness & damping coefficient of 1,000 lb/in. & 20 lb-s/in., respectively
- Other than struts, isolation model is same as baseline; 9-strut configuration with CEV CM location consistent with 606B design

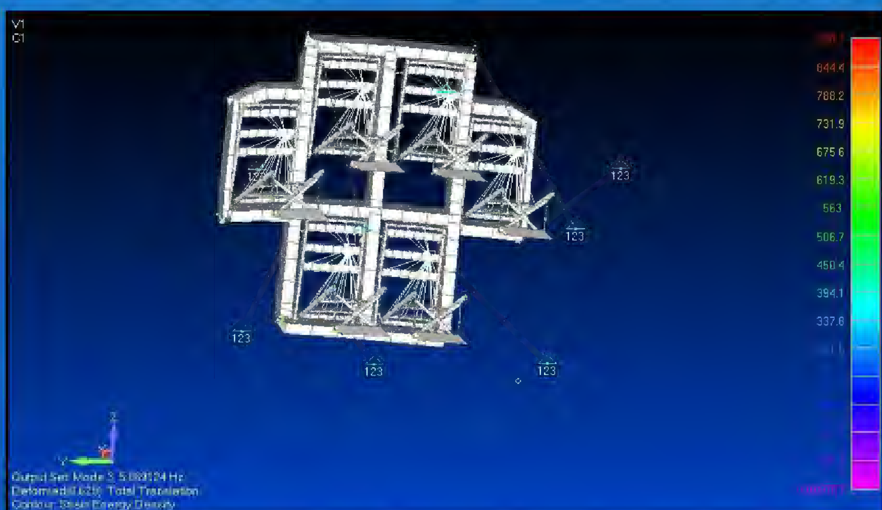
1,000 lb/in. Isolation Struts



F1 = 3.8 Hz



F2 = 3.9 Hz



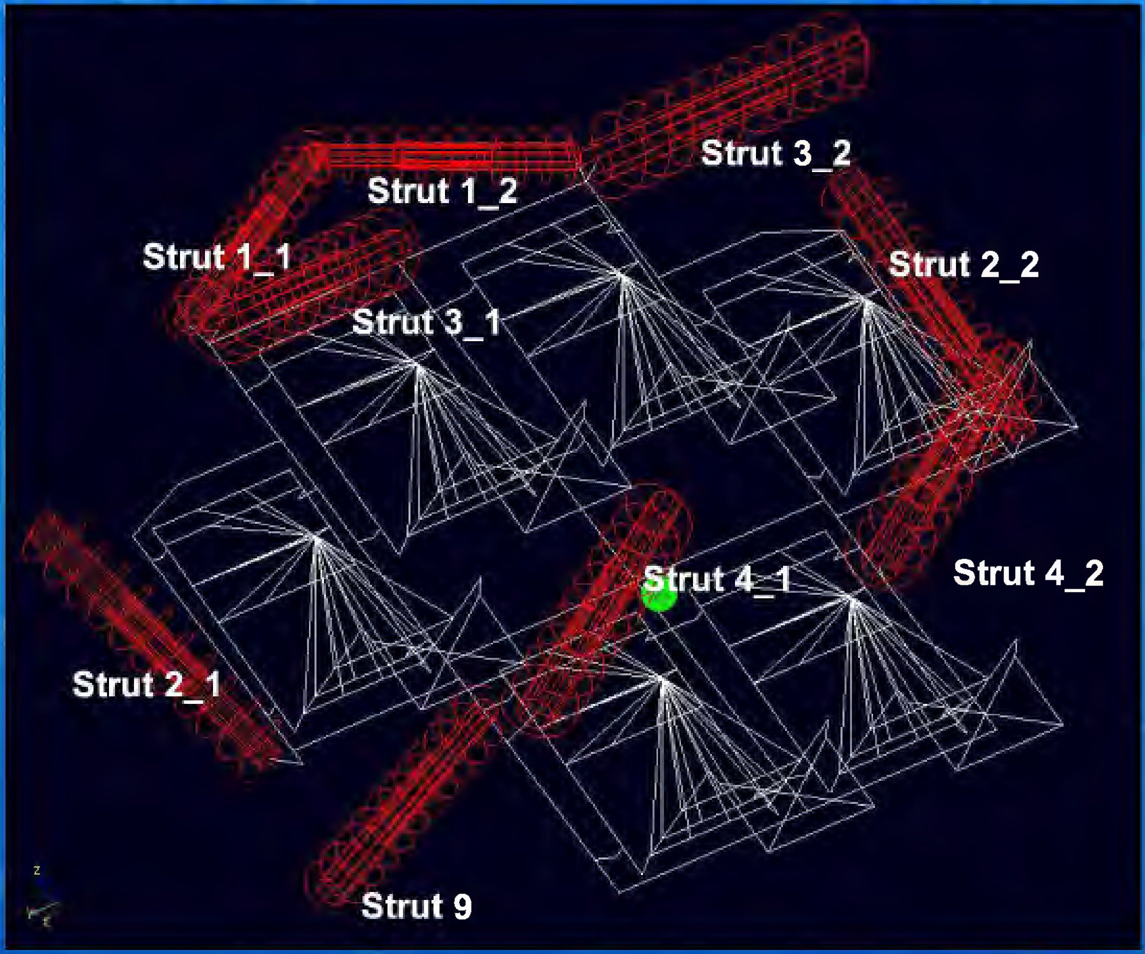
F3 = 5.1 Hz

- Softened struts move fundamental modes below excitation frequencies
- System acts as low pass filter. Pallet moves as rigid body

ADAMS Isolation Model

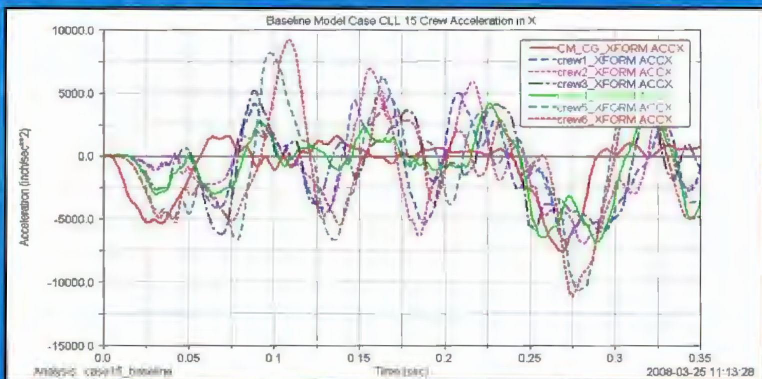
- Coordinate System:
  - X direction – frontal impact
  - Y direction – side impact
  - Z direction – spinal impact

- Strut direction
  - 1_1 & 1_2 = Y & Z direction
  - 2_1 & 2_2 = Z direction
  - 3_1 & 3_2 = X direction
  - 4_1 & 4_2 = X direction
  - 9 = Y direction

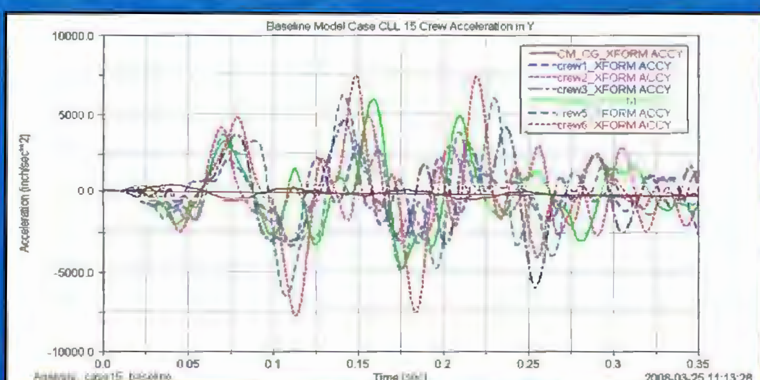


Comparison of Baseline 606 & Isolated (Reduced Model): CLL Case 15

Baseline model results

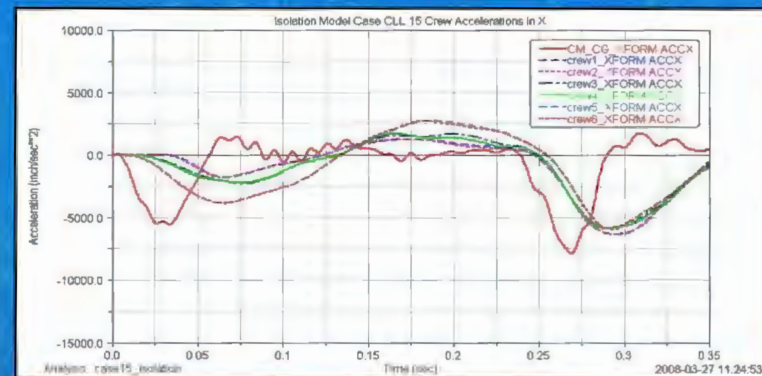


Max crew X acceleration (frontal impact) = 11,123 in./s² or 28.8 G

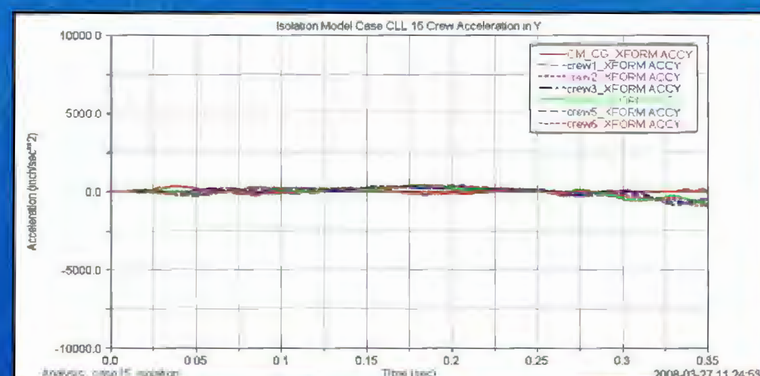


Max crew Y acceleration (side impact) = 7,741 in./s² or 20 G

Isolation model results



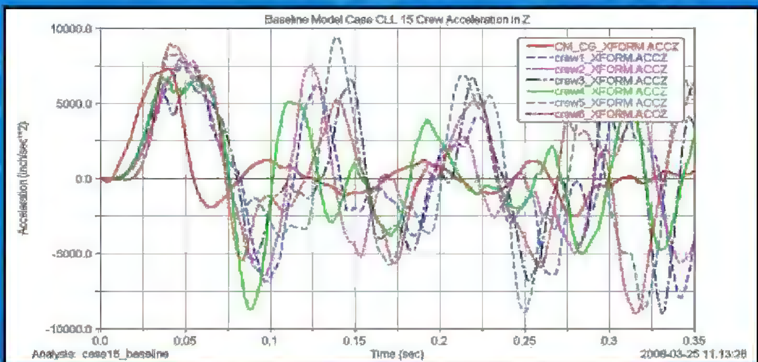
Max crew X acceleration (frontal impact) = 6,316 in./s² or 16.36 G



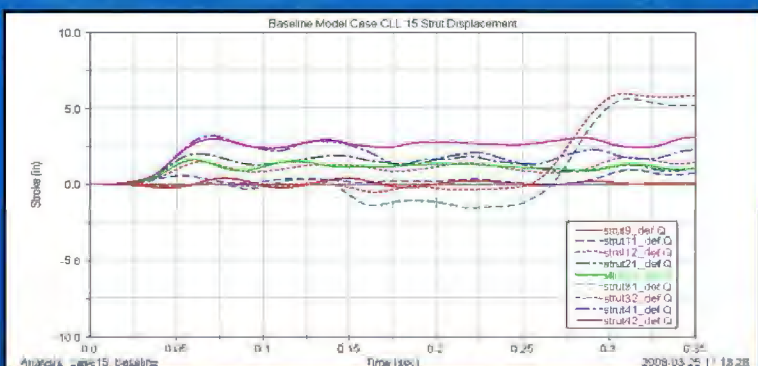
Max crew Y acceleration (side impact) = 907 in./s² or 2.3 G

Comparison of Baseline 606 & Isolated (Reduced Model): CLL Case 15 (cont.)

Baseline model results

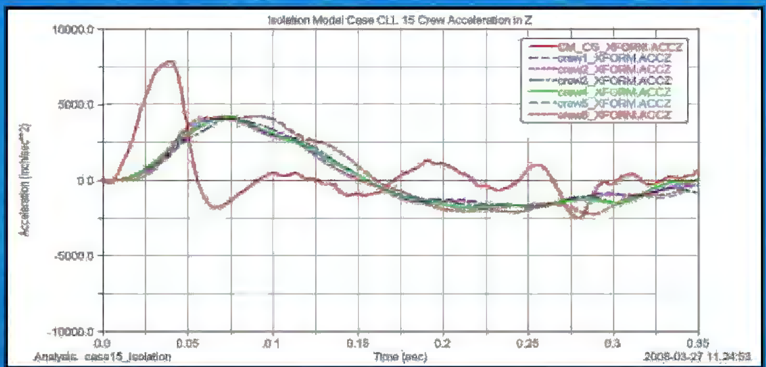


Max crew Z acceleration (frontal impact) = 9,454 in./s² or 24.5 G

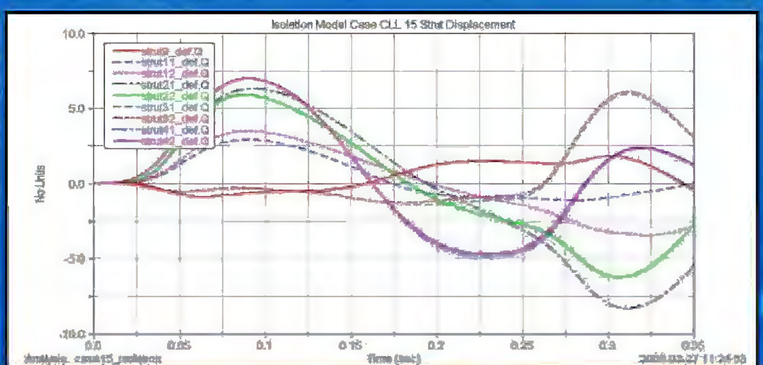


Max strut displacement = 5.96 in.

Isolation model results



Max crew Z acceleration (frontal impact) = 4,244 in./s² or 11 G



Max strut displacement = 8.33 in.

Conclusions: Isolation vs. Baseline

- Baseline model with friction struts actually amplifies CG loads onto crew. There is attenuation when CG accelerations are very high; otherwise all loads are amplified, not attenuated. Thus, crew loads would be reduced in most cases if crew was rigidly attached to CEV CG
- Isolation (only) model shows great promise in reducing dynamic loading of crew accelerations. Isolation model strokes more than baseline model but remains under allowable 8 in. for most cases except CLL 21 & 23. More work required to meet all cases
- Values of k & c for isolation struts must be optimized to stay within allowable stroke limits
- Potential design solution using both attenuation & isolation
  - Attenuation (stroke) used for absorption of impact energy to lower acceleration
  - Isolation (low frequency) used to reduce dynamic amplification from Orion structure to crew

Brinkley Model Results Case CLL 15 (Input from ADAMS Reduced Model)

- Brinkley model crew accelerations were used to obtain more accurate Brinkley injury criteria results

Comparison Between Baseline and Isolation Models' Response to CLL Case 15				
	X Axis Risk	Y Axis Risk	Z Axis Risk	High Risk Injury Criteria (>1 shows high risk)
Baseline Model				
Crewman 1	Low	Very Low	High	0.93
Crewman 2	Low	Very Low	High	0.89
Crewman 3	Moderate	Very Low	High	1.07
Crewman 4	Moderate	Very Low	High	1.03
Crewman 5	Moderate	Very Low	High	0.93
Crewman 6	Low	Very Low	High	0.84
Isolation Model				
Crewman 1	Low	Very Low	Very Low	0.58
Crewman 2	Low	Very Low	Very Low	0.58
Crewman 3	Low	Very Low	Low	0.69
Crewman 4	Low	Very Low	Low	0.68
Crewman 5	Low	Very Low	Very Low	0.59
Crewman 6	Low	Very Low	Very Low	0.57

Problem Summary

Problem Summary

- System goal:
  - Develop best occupant protection system possible for Orion that maximizes crew safety during ascent, ascent aborts (if required), landing (water nominal with land landing contingency) & post-landing recovery
- Innovative engineering is required to solve this complex system problem
- Tools used for this challenge include:
  - Basic math modeling tools such as Excel & hand calculations
  - Computer aided design (CAD) such as ProE or SolidWorks
  - Finite element analyses (FEA) such as NASTRAN, ADAMS, LS-Dyna
  - Unique analysis tools such as Brinkley (Crew Injury Probability) software
- Problem considerations include:
  - "Out of box" thinking
  - Explore wide range of options & evaluate through analyses & engineering data
  - Design concepts should include hardware that is readily available
  - Understand system perspective & effect on other systems