Design and Fabrication of a HIC Compliant Bulkhead

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Problem Statement

- The compliance with the Head Injury Criteria (HIC) poses a significant problem for aerospace industry

$$HIC = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)\,dt \right\}^{2.5} \right]_{max}$$

Where, a(t) is the head resultant acceleration of the Part 572 Hybrid II ATD in g's and t_1 and t_2 are the response times to maximize the function.

Non injurious if : HIC < 1000

- **HIC problems encountered in:**

Bulkhead
Cabin Furnishings
Cabin Side Walls
Instrument Panel
Wind Screen Posts/Side Posts
Class Dividers
Cockpit Glare Shields
Row-to-Row
Entry Door Steps




Development Of HIC Compliant Bulkhead

Goal

- *Proof of concept*: It is possible to arrive at a potential solution for bulkhead seating problem that is acceptable to the industry such that *HIC* < 1000

$$HIC = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)\,dt \right\}^{2.5} \right]_{max}$$

Benefit

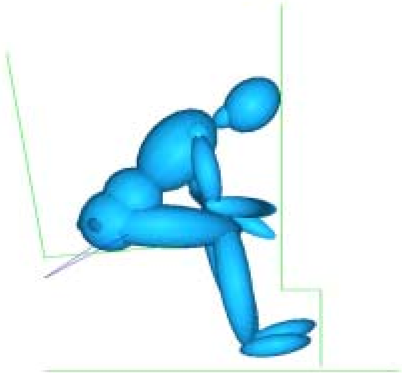
- Project contributes to aircraft safety by providing potential solution(s) for occupants head injury protection

Products

- A prototype HIC compliant bulkhead
- Methodology and guidelines for industry

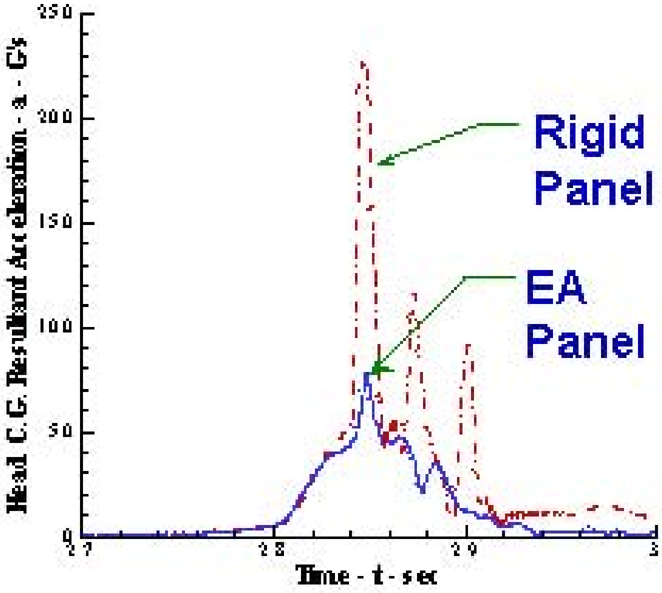
Static Testing

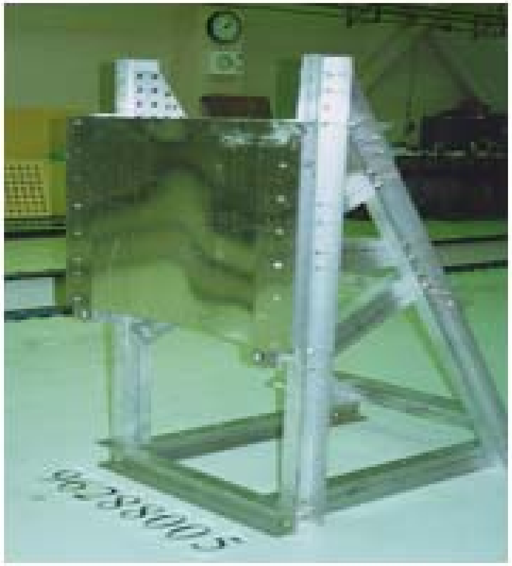
Dynamic full-scale sled testing



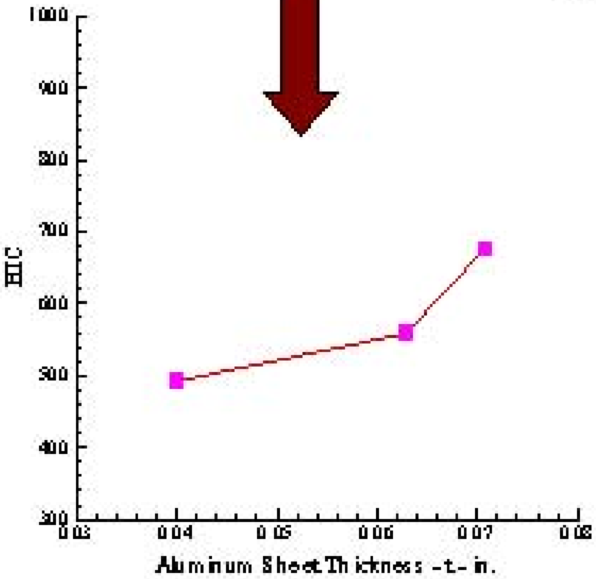
Correlation between tests and analytical models

Energy - Absorbing Panels



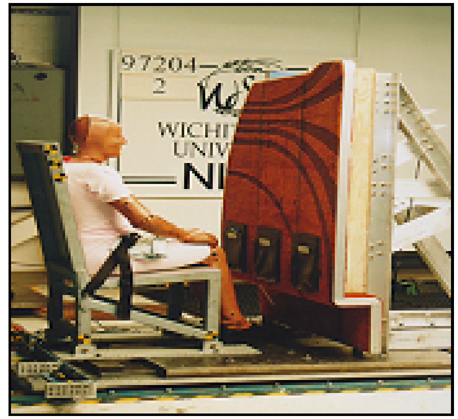


Aluminum sheet Panel



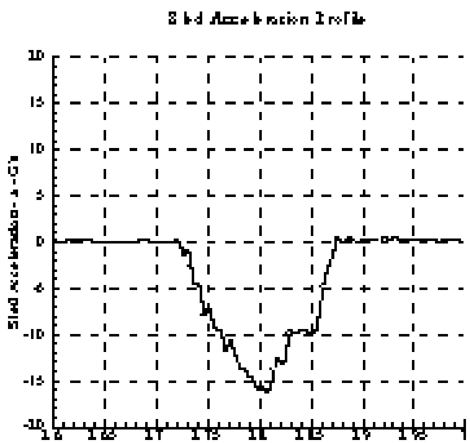
Thin Panel designs consistently produced HIC below 1000

Baseline Tests – Typical Production Bulkhead



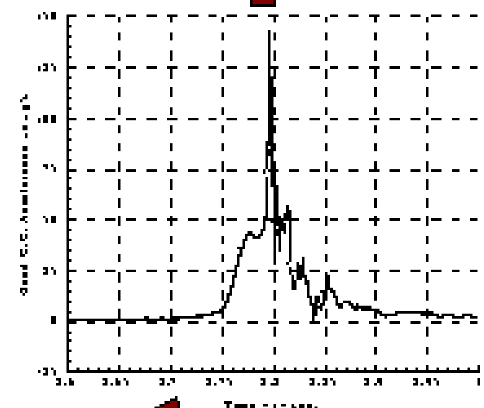
Production bulkhead panels

Dynamic sled test



16g dynamic test pulse

Analysis of head impact

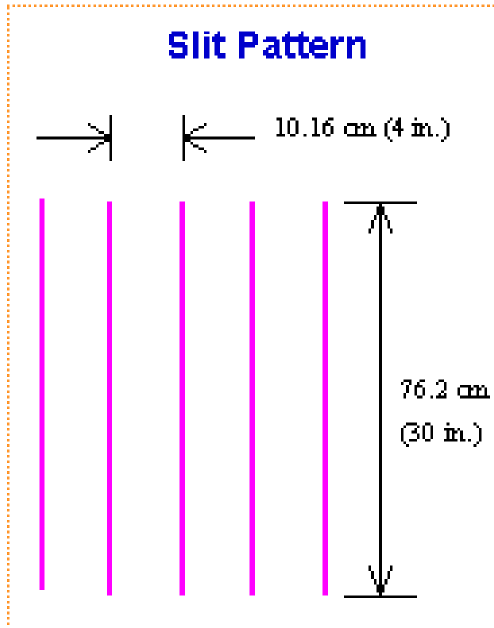


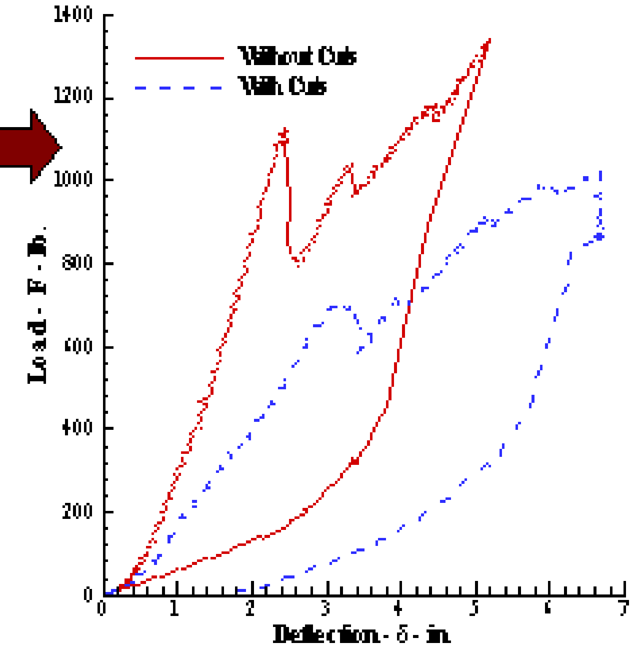
HIC >1000

Modification Of Production Bulkheads

Initial stiffness 470 lb./in

Initial stiffness 212 lb./in

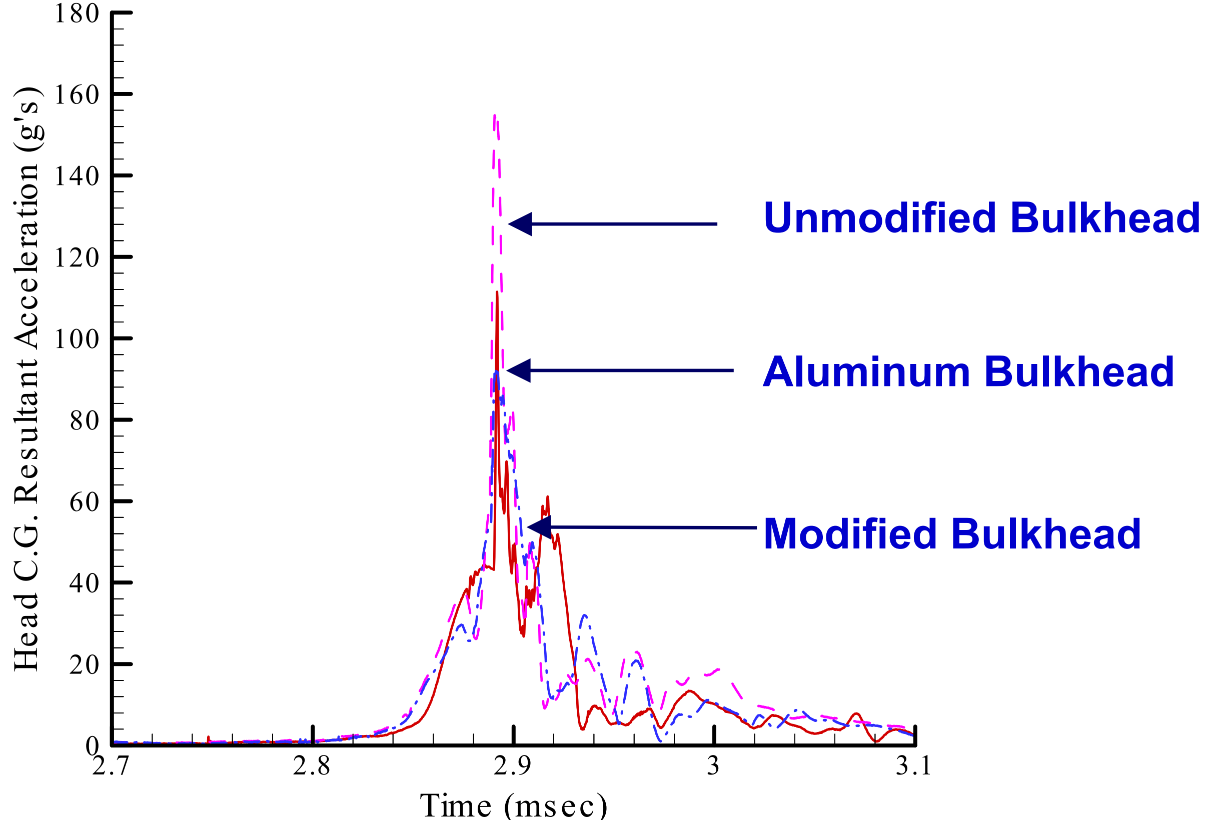




30-in. vertical slits at 4 in. apart on the face sheet and carpet

Vertical cuts reduced the stiffness of the panels and HIC < 1000

Dynamic Test Results Comparison

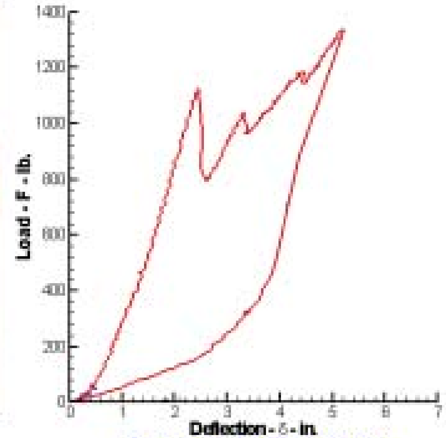


Results	Aluminum Bulkhead	Unmodified Bulkhead	Modified Bulkhead
Peak Head Accl.(g)	111	156	92
HIC	653	1395	881
HIC WINDOW(ms)	49	12	31

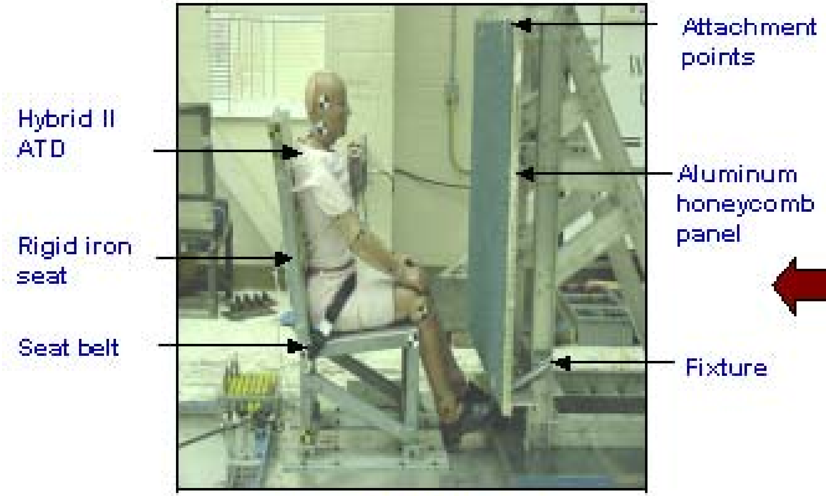
Validated Analytical Model

- Biodynamic models were developed and validated against dynamic sled tests
- Static tests were conducted to obtain load-deflection properties of the bulkhead

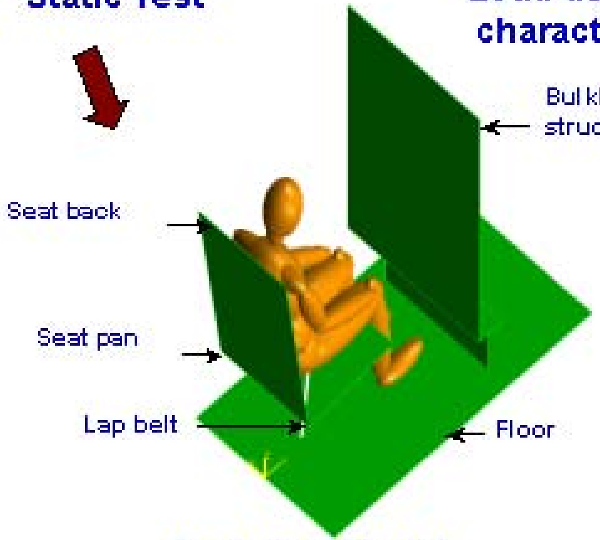
Static Test



Load-deflection characteristics

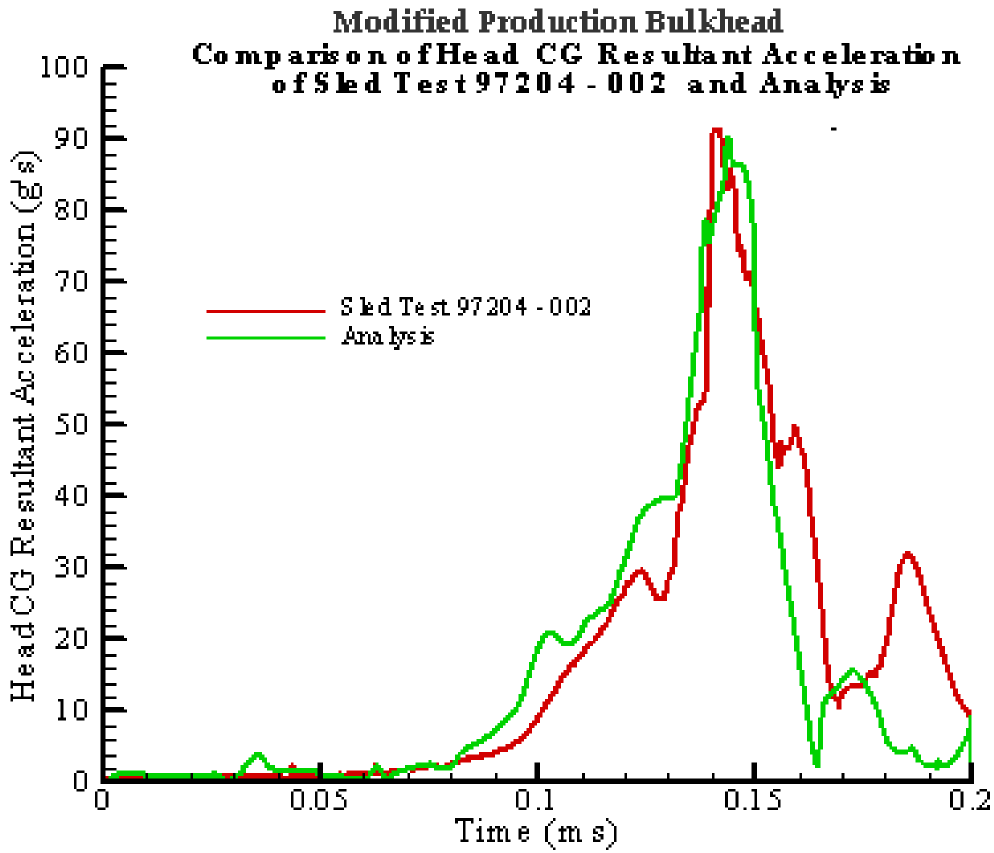


Dynamic Sled Test



Analytical Model

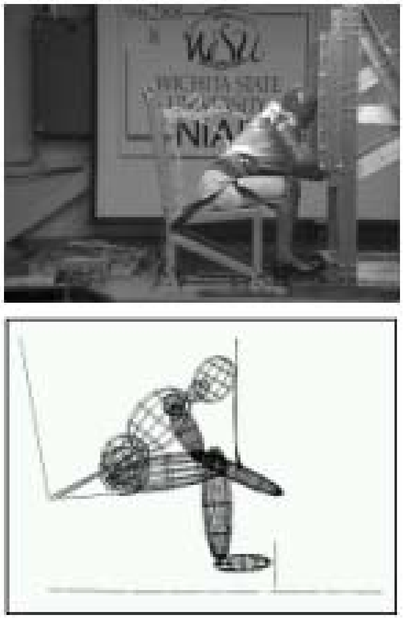
Sample Analytical and Dynamic Test Results Comparison



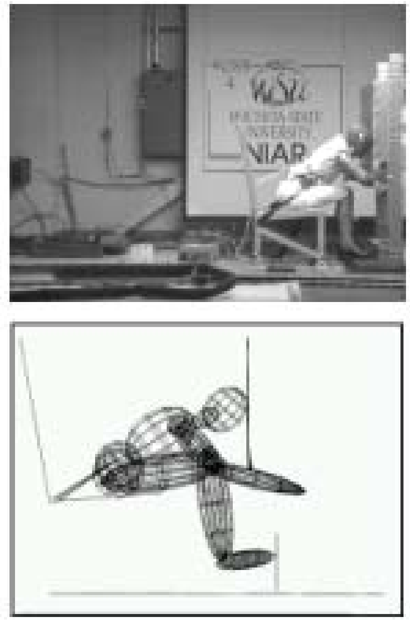
Head C.G Average Acceleration (g's)		Head C.G Peak Acceleration (g's)		Δt (ms)		HIC	
Test	Analysis	Test	Analysis	Test	Analysis	Test	Analysis
42	41	93	91	31	22	881	884

ATD Response for Different Seat Setbacks

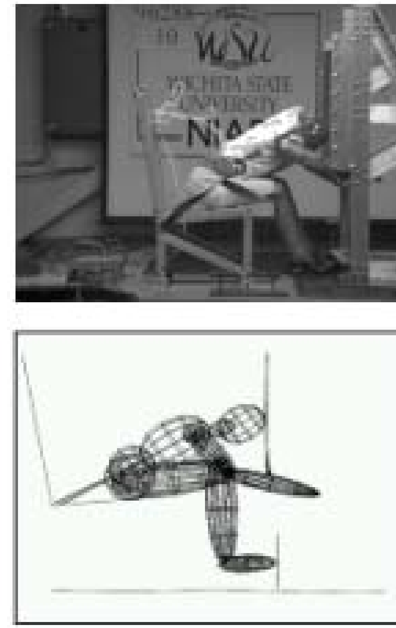
Dynamic Sled Tests on Aluminum Panels



Seat setback 33 in.



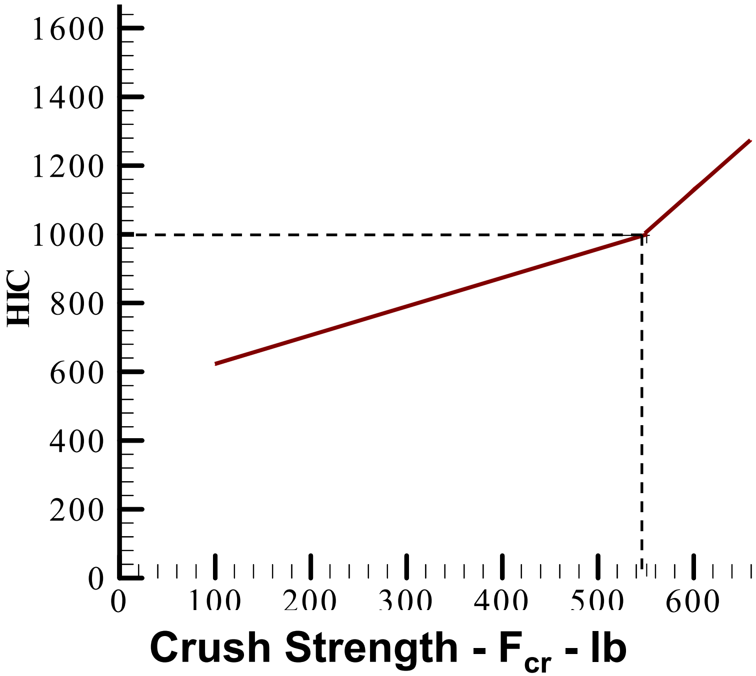
Seat setback 35 in.



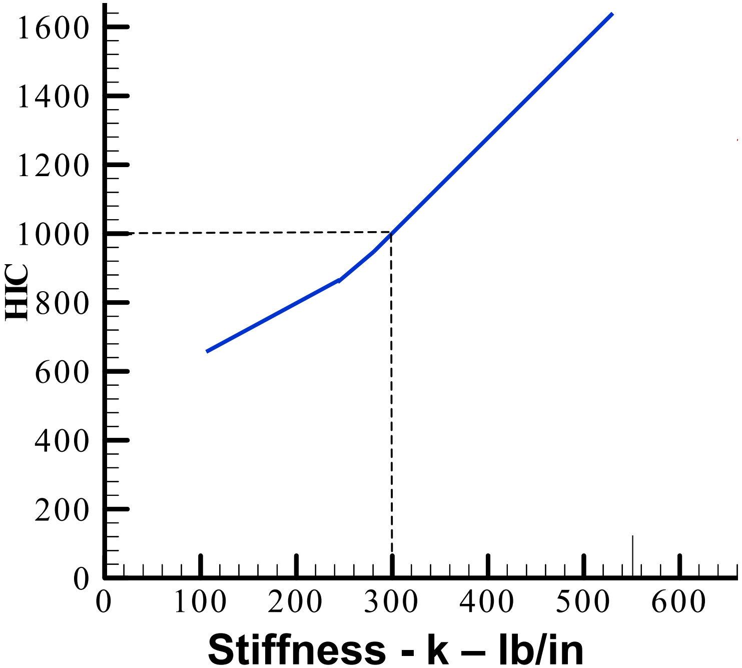
Seat setback 38 in.

Seat setback (In.)	Head Impact Velocity (ft/s)		Head Impact Angle (deg)		Head C.G Peak Accel. (g's)		HIC	
	Test	Analysis	Test	Analysis	Test	Analysis	Test	Analysis
33	46	45	32	32	168	166	**835**	918
35	46	47	34	40	141	140	**581**	620
38	48	48	67	60	81	80	**552**	560

Design Guidelines for HIC Attenuation



Variation of Crush Strength

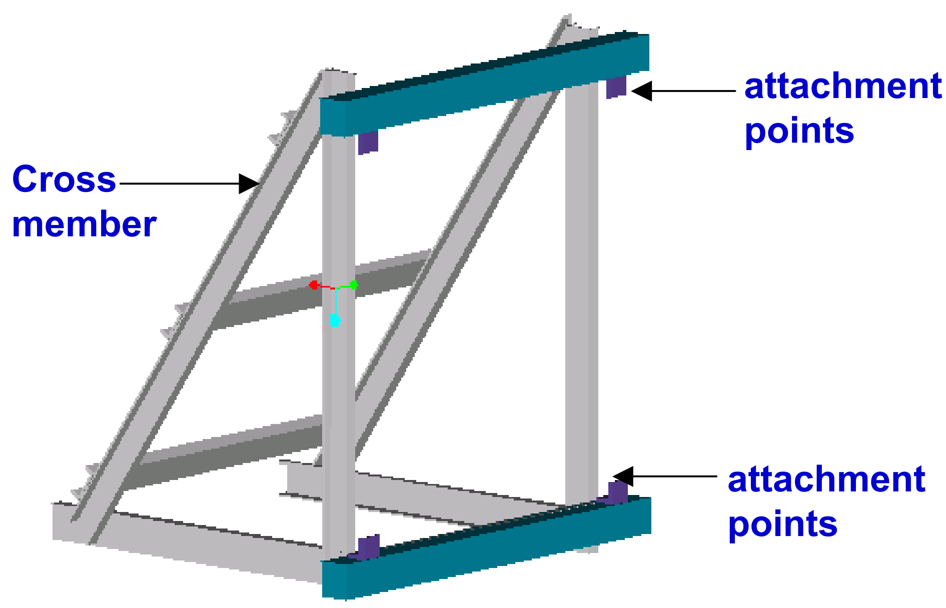


Variation of stiffness

- Validated biodynamic model was used for the development of the design guidelines
- Parametric studies were conducted to study the variation of HIC by varying crush strength and stiffness values

Fabrication of test rig

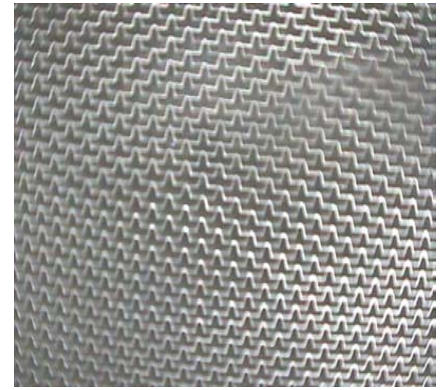
- The existing test rig was modified to replicate proper attachment points
- Modifications were made to the rig to ensure that no additional support was provided to the bulkhead



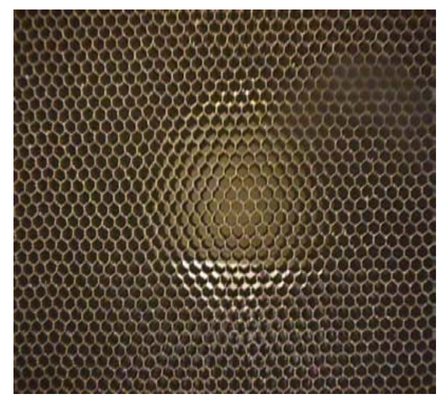
Modification of attachment points on the test rig

Bulkhead Materials

- Bulkhead panel composition
  - **Honeycomb core**
  - **2-ply Epoxy fiberglass face sheets**
  - **Covered with carpet used typically in aircraft installations**
- Selected based on design guidelines and from sled tests conducted at NIAR and CAMI
- Both metallic and non-metallic cores were studied for the design of the bulkhead



Metallic cores

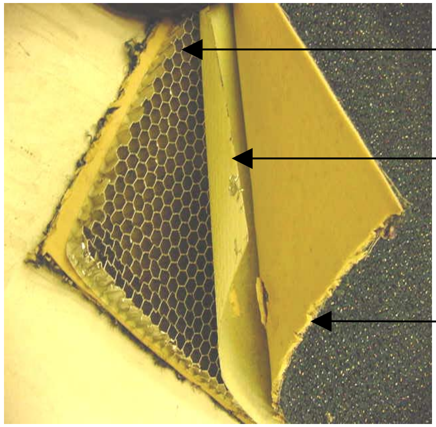


Non-Metallic cores

Composition and Properties of Bulkhead Panels

Bulkhead Panel Composition

	First Series	Second Series	Third Series
Bulkhead Series	**TEKLAM N510**	**TEKLAM N510E**	**TEKLAM**
Core	Nomex Honeycomb	Nomex Honeycomb	Aluminum Honeycomb
Facings	2-ply Phenolic Fiberglass	2-ply Epoxy Fiberglass	Fiberglass
Carpet	No	Yes	Yes



Lay-up of the bulkhead panel-
TEKLAM III Series

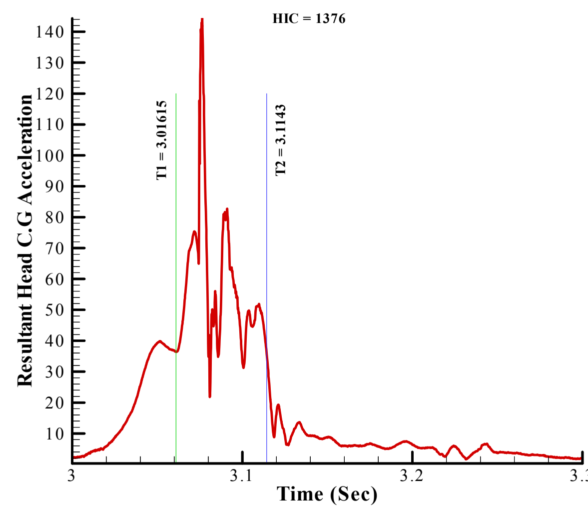
Properties of the acquired panels

		First Series	Second Series	Third Series
Property	**Unit**	**TEKLAM N510**	**TEKLAM N510E**	**TEKLAM**
Thickness	in	1.000	1.000	1.000
Weight	lb/sq ft	0.74	0.74	0.74
Facings	in	0.04	0.04	0.04
Core	in	1/8	1/8	3/8
Flat wise Compression	psi	310	275	240
Density	psi	3.0	2.0	2.0

Dynamic Tests with First Series of Bulkheads

- Dynamic sled tests were conducted at NIAR on the first series of bulkheads, the stiffest ones, to evaluate the performance of these bulkheads for accelerations in the head of 49 CFR Part 572, Subpart B of the ATD

Sled test # 01008-2



Resultant head acceleration

Test Results

Seat Setback	HIC	Δt (ms)	Avg. Accl. (g)
33	1550	69	55.1
35	1450	71	52.8

∴ **First series of bulkheads failed**

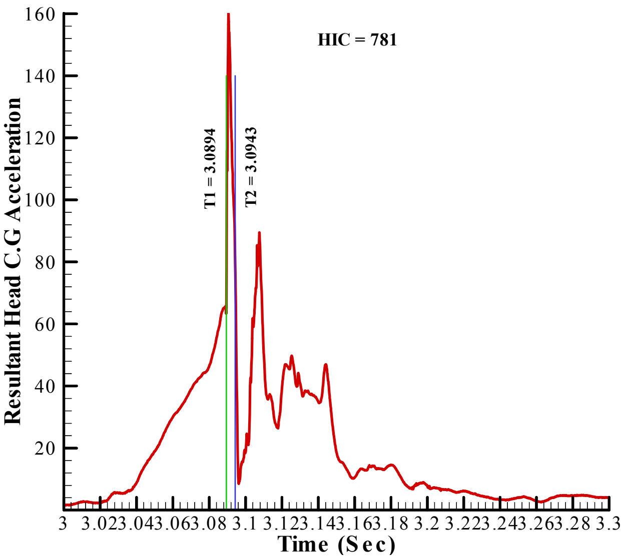
Dynamic Tests with Second Series of Bulkheads

- Dynamic sled test was conducted on the second series of bulkheads to determine head accelerations
- Bulkheads less stiff than the first series bulkheads

Sled test # 01008-4

Test Results

Seat Setback	HIC	Δt (ms)	Avg. Accl. (g)
33	1321	21.4	82.4
35	781	4.9	118.8

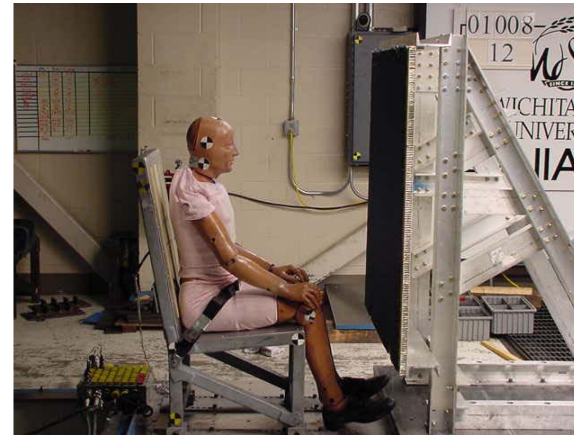


Resultant head acceleration

∴ **Second series of bulkheads failed**

Dynamic Tests with Third Series of Bulkheads

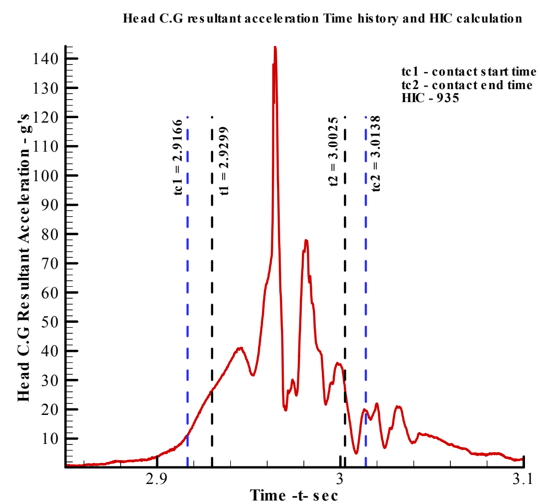
- Sled tests conducted at both smaller and larger seat setback distances
- HIC values obtained below the threshold value of 1000 for both seat setback



Sled test # 01008-12

Test Results

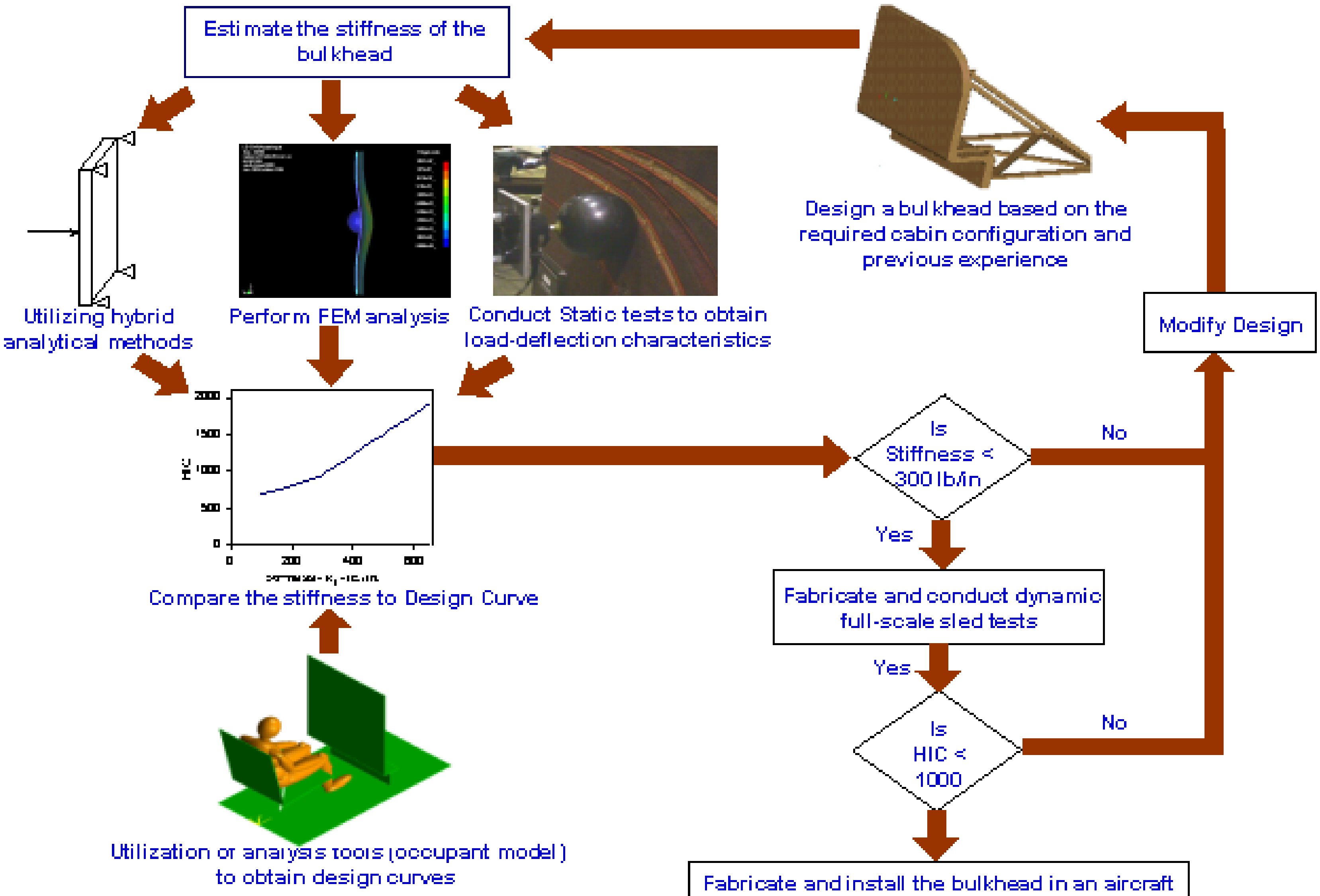
Seat Setback	HIC	Δt (ms)	Avg. Accl. (g)
33	935	22	62.8
35	165	23.3	35.3



Resultant head acceleration

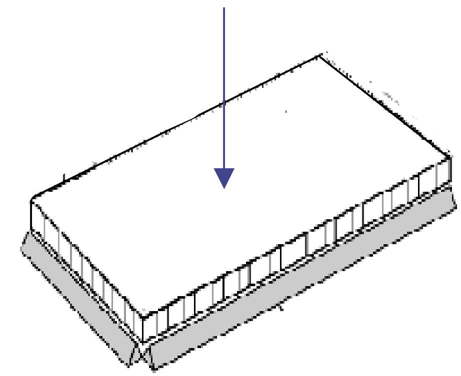
∴ The ***proof of concept*** is demonstrated

Design Methodology



Hybrid Analytical Method to Estimate Stiffness

SIMPLY SUPPORTED RECTANGULAR PLATE :



- Stiffness value at any point (x,y) :

$$k = \frac{P}{W} = \frac{\pi^4 abD}{4\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{\sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)}{\left(\frac{m^2}{a^2}+\frac{n^2}{b^2}\right)}\sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)}$$

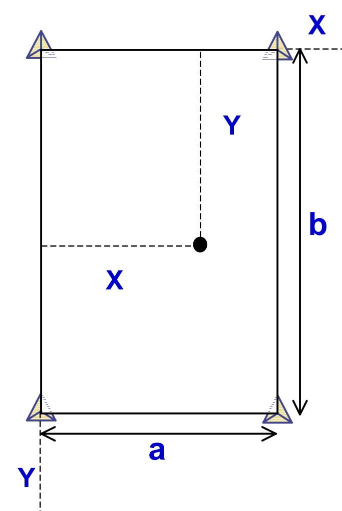
Where :

P : Load
W : Deflection
D = EI : Bending Rigidity
E : Young's Modulus
I : Second Moment of Area
m , n = 1,3,5… (convergence for three or four terms)

- e.g., the stiffness at the center of a square plate :

$$k = \frac{D}{0.0112\ a^2}$$

- The estimated stiffness is compared to the values in the design curve(s)
- Other boundary conditions yield similar formulations for the stiffness values



Stiffness of a simply supported plate under concentrated load at any point

Hybrid Analytical Method to Estimate Stiffness (cont'd)

COMPOSITE PLATES :

- For each ply (lamina), stiffness Q in the fiber and transverse directions:

$$Q_{XX} = mE_X$$
$$Q_{YY} = mE_Y$$
$$Q_{XY} = m\,\upsilon_Y E_X$$
$$Q_{YX} = m\,\upsilon_X E_X \quad \text{where,} \quad m = [\,1 - \upsilon_X \upsilon_Y\,]^{-1}$$

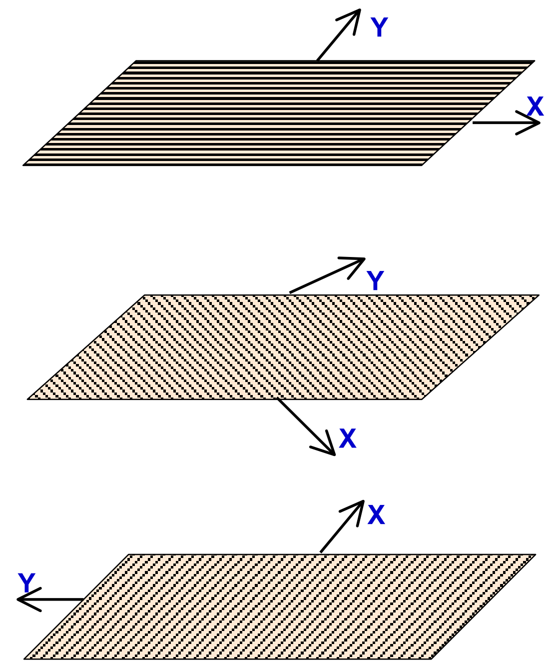
- Transforming to direction 1 – 2

For 0° ply : $Q_{11} = Q_{XX}$
For 45° ply : $Q_{11} = \frac{1}{4} Q_{XX} + \frac{1}{4} Q_{YY} + \frac{1}{2} Q_{XY} + Q_{YX}$
For 90° ply : $Q_{11} = Q_{YY}$

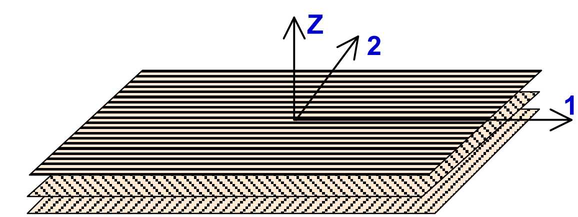
- Equivalent stiffness / Bending Rigidity for the combined laminate :

$$D_{11} = \int Q_{11} z^2 dA$$

- The value of D is replaced by D_{11} in the previous plate stiffness calculation
- The estimated stiffness is compared to design curve(s)



Ply (Lamina)



Laminate

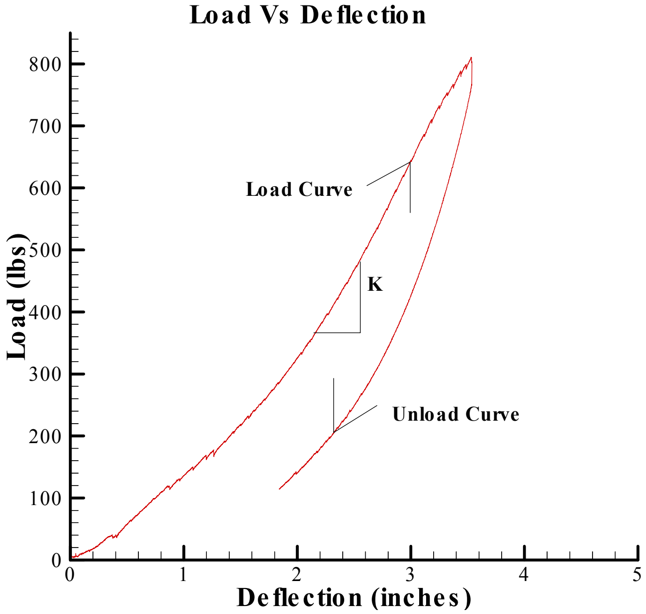
Finite Element Analysis to Estimate Stiffness

Perform FEM analysis

- Finite Element Analysis can be performed on a bulkhead design to estimate the stiffness at the vicinity of the head impact
- The estimated stiffness is compared to the design curve(s)

Static Test to Evaluate Stiffness

Static testing on bulkheads to obtain load-deflection characteristics



Sample load-deflection characteristics and bulkhead stiffness

- For more complex compositions of the bulkhead materials and geometries, the bulkhead needs to be fabricated first
- Static test is conducted on a fabricated bulkhead to evaluate the stiffness at the point of impact
- The stiffness value is compared to the design curve(s)

Concluding Remarks

- HIC compliant bulkheads were designed, fabricated and tested for aircraft interior installation.
- A design methodology was developed for the development of HIC compliant bulkheads.
- The methodology requires estimation of the stiffness of the designed bulkhead. The estimated stiffness will be compared to the ones from the design curve(s) for HIC attenuation.
- Stiffness of the Teklam panels will be estimated/evaluated and plotted vs. the design curve(s)
- Project highlight's the FAA's main objective of enhancing passenger safety.