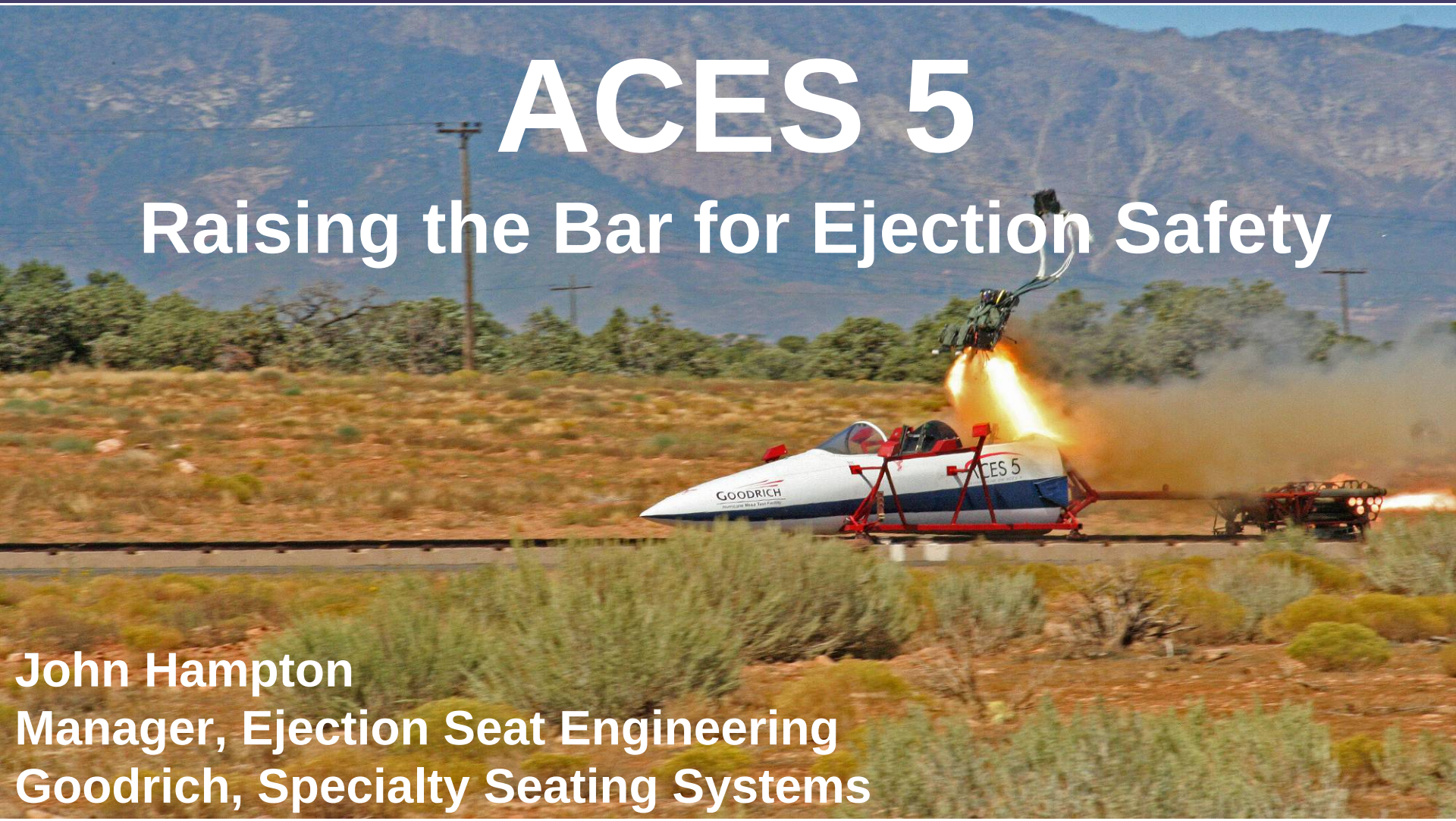
ACES 5

Raising the Bar for Ejection Safety



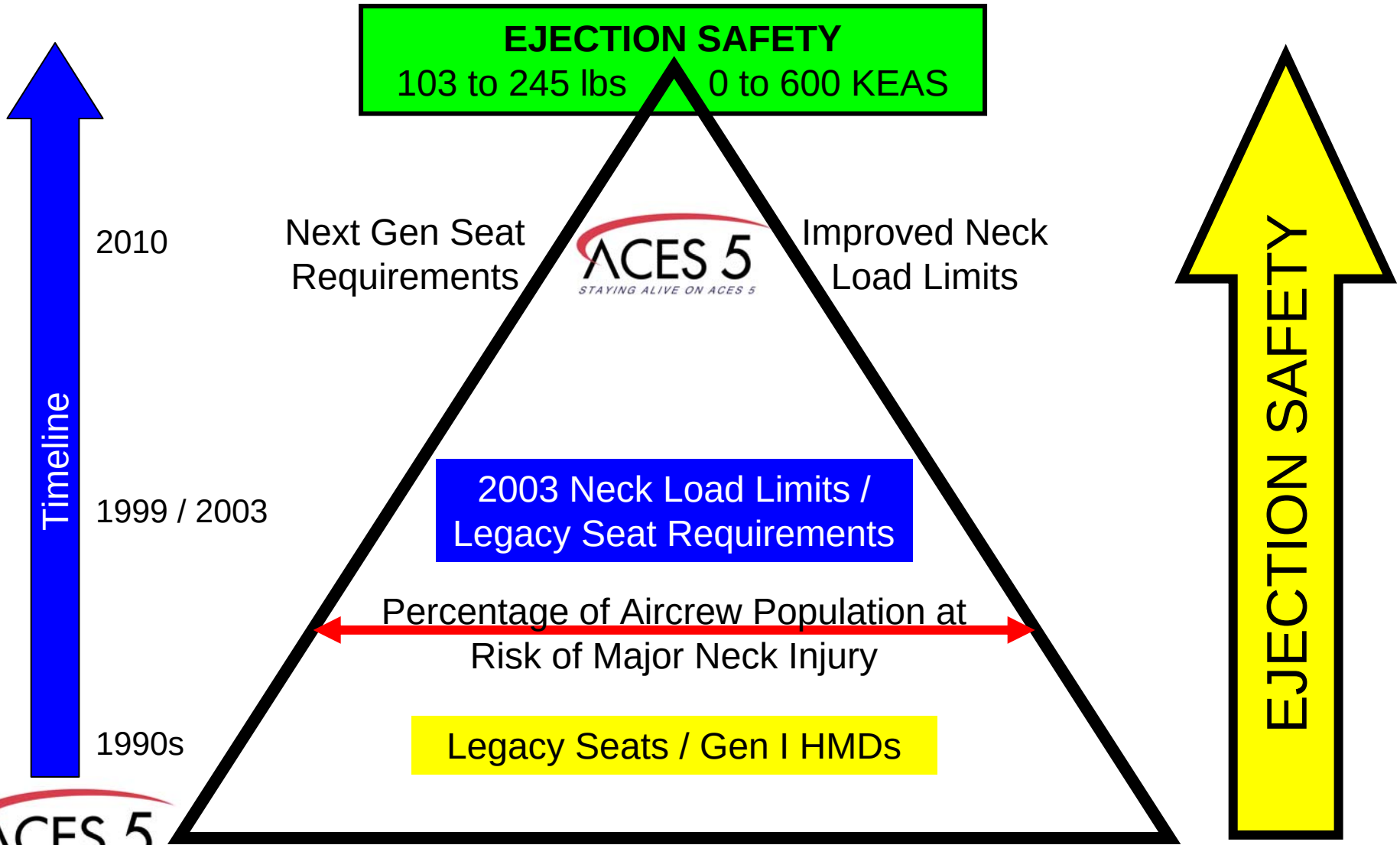
John Hampton
Manager, Ejection Seat Engineering
Goodrich, Specialty Seating Systems

right attitude/right approach/right alongside

www.goodrich.com

GOODRICH

ACES 5 – Raising the Bar for Ejection Safety
Head / Neck Loading



2003 Neck Load Requirements

- **Why were new neck load requirements needed?**
  - **Expanded aircrew population – 103 to 245 lbs**

  - **Helmet Mounted Display (HMD)**
    - **Increased mass (approx 5 lbs of head supported mass)**
    - **Forward centre of gravity (CG) position (approx 2 lbs added to the front of the helmet)**
    - **Increased moment of inertia (MOI)**
    - **Degraded aerodynamic profile (longer helmet)**

2003 Neck Load Requirements

- **What are the 2003 Neck Load Requirements?**
  - **Partly based on automotive neck injury limits**
  - **Intended to define a 10% risk of a major neck injury, Abbreviated Injury Scale (AIS) 3 injury**
  - **Expanded to cover the lower neck and off axis MIx & MIz moments**
  - **Detailed in SAFE 2006 paper by Jeff Nichols titled *"Overview of Ejection Injury Criteria"*, summarized in next slide**

2003 Neck Load Requirements

Notes:

1. Limits apply up to 450 KEAS. Above 450 KEAS case 6 limits apply to all aircrew sizes.
2. Extension critical intercept used as the denominator for MIx & MIz moment indices where there is no automotive basis

	Case 1		Mid Male		Case 6	
Weight	**103 lbs**		**172 lbs**		**245 lbs**	
Sitting Height	**32**		**35.7**		**38**	
	Time (ms)	Load (lbs)	Time (ms)	Load (lbs)	Time (ms)	Load (lbs)
Tension	5	414	5	618	5	761
	31	414	35	618	37	761
	40	200	45	320	48	450
	80	200	80	320	80	450
Compression	5	519	5	790	5	979
	27	200	30	320	32	450
	80	200	80	320	80	450
Upper Neck Shear	5	405	5	625	5	777
	20	225	25	337	28	414
	29	225	35	337	39	414
	37	165	45	247	50	304
	80	165	80	247	80	304
Lower Neck Shear	5	810	5	1250	5	1554
	20	450	25	674	28	828
	29	450	35	674	39	828
	37	330	45	494	50	608
	80	330	80	494	80	608
Critical Intercepts						
Tension (lbs)	964		1530		1847	
Compression (lbs)	872		1385		1673	
Flexion (in.lbs)	1372		2744		3673	
Extension (in.lbs)	593		1195		1584	
Upper Neck Nij	0.5		0.5		0.5	
Upper Neck MIx	0.5		0.5		0.5	
Upper Neck MIz	0.5		0.5		0.5	
Lower Neck Nij	1.5		1.5		1.5	
Lower Neck MIx	1.5		1.5		1.5	
Lower Neck MIz	1.0		1.0		1.0	

Ref: Nichols JP. Overview of ejection neck injury criteria. Proceedings of the 44th Annual Safe Association Symposium; 2006 October; Reno, NV. Creswell, OR: SAFE; 2006

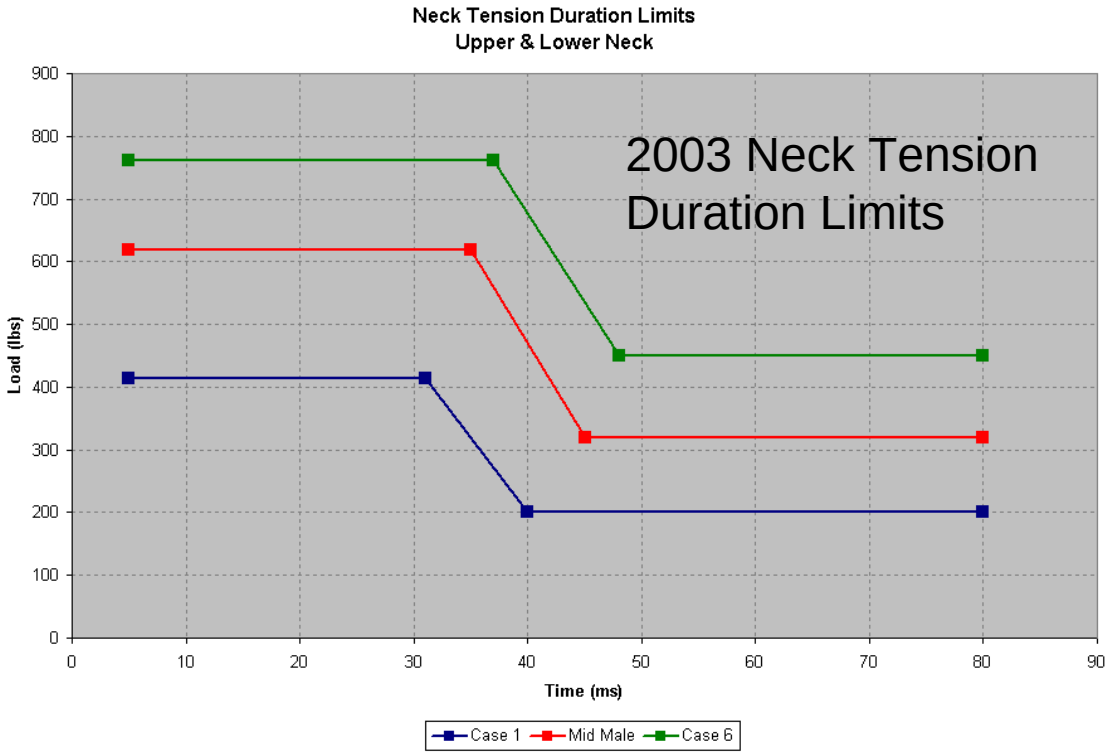
2003 Neck Load Requirements

- What are the areas where the 2003 Neck Load Requirements could be improved?
- Why do they not provide for safe escape for all aircrew?
  - Case 6 neck injury limits are applied to all aircrew above 450 KEAS
  - Out of position / off axis moments and their combination with axial loads is not adequately covered
  - Recent research and testing shows that 2003 requirements under predict injury in some areas

2003 Neck Load Requirements

Issue 1- NIC Limits above 450 KEAS

- **Case 6 neck load limits are applied to all aircrew weights and sizes above 450 KEAS**
  - **Risk of major neck injury (AIS 3+) increased for pilots weighing less than 245 lbs**
  - **Mid male (172 lbs) could be exposed to 761 lbs of neck tension when the short duration tension limit for the mid male is 618 lbs**
  - **Small female (103 lbs) could be exposed to 761 lbs of neck tension when the short duration tension limit for the small female is 414 lbs**

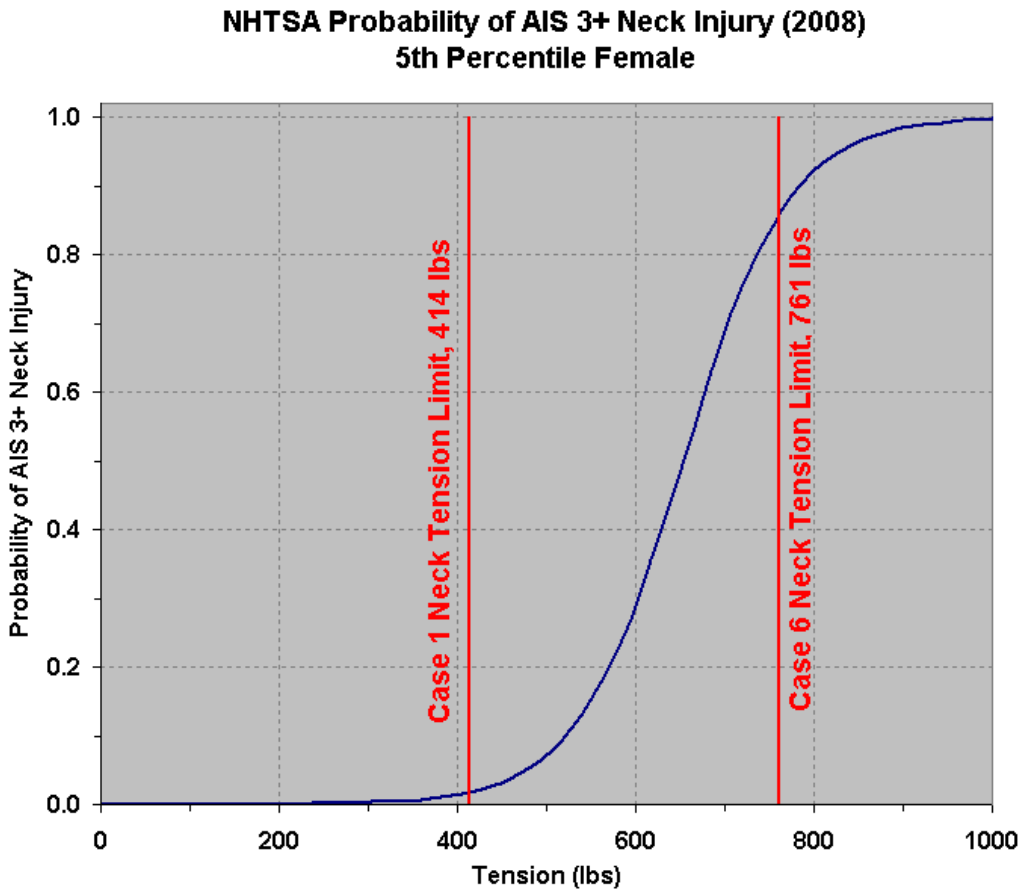


2003 Neck Load Requirements

Issue 1- NIC Limits above 450 KEAS

- **For the small female the risk of a major neck injury (AIS 3+) increases significantly after 500 lbs of tension, and at the case 6 short duration tension limit of 761 lbs the probability of a major neck injury (AIS 3+) is 86%**

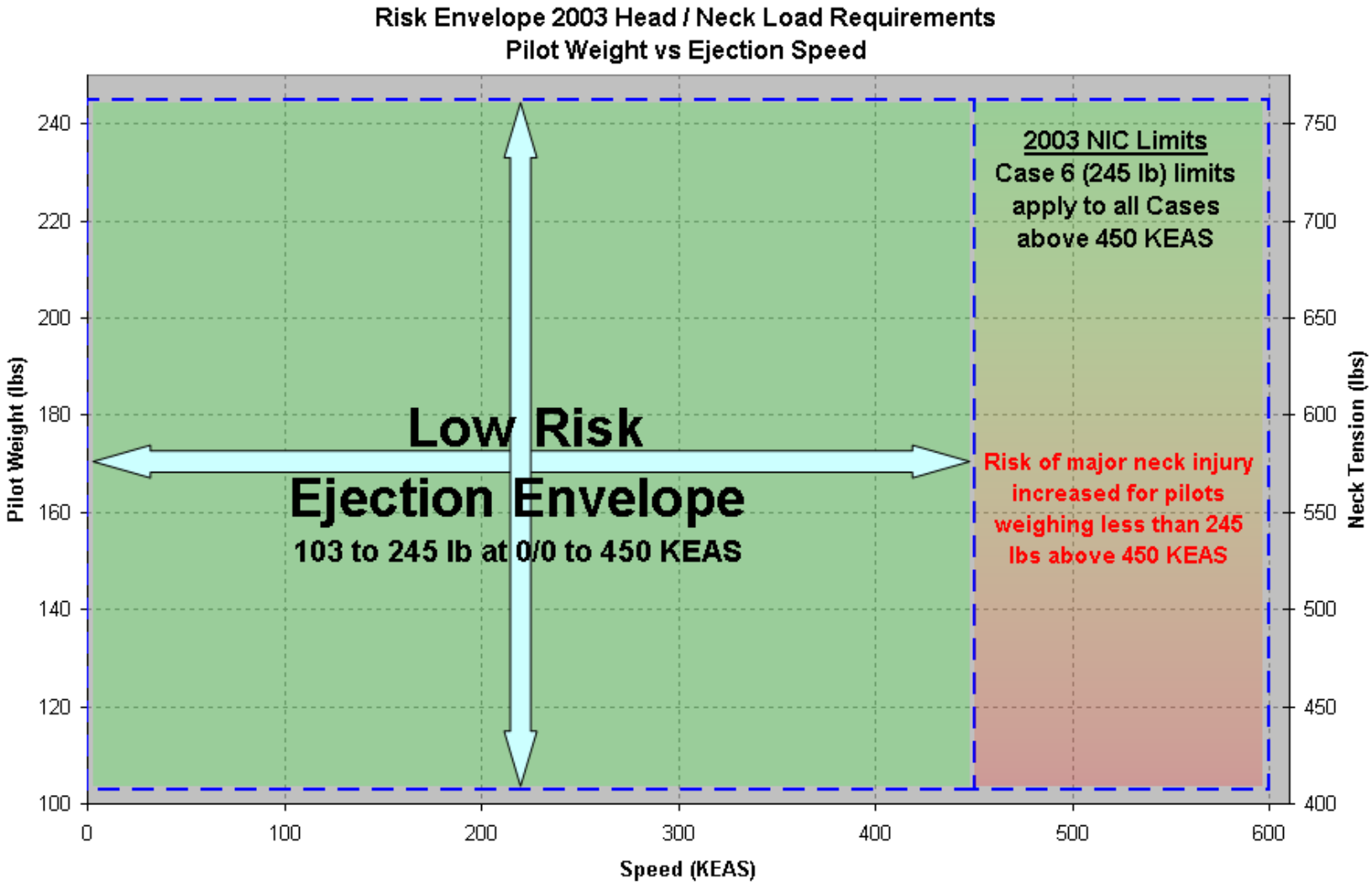
The latest National Highway Traffic Safety Administration (NHTSA) major neck injury probability chart for upper neck tension for the small female is shown opposite with the 2003 short duration neck tension limits for case 1 and case 6 included (Ref 1)



Ref 1: Laituri TR, Henry S, Kachnowski B, Sullivan K. A Initial Assessment of Next-Generation USA Frontal NCAP:Fidelity of Various Risk Curves for Estimating Field Injury Rates of Belted Drivers. SAE International, Warrendale PA, 2009-01-0386

2003 Neck Load Requirements

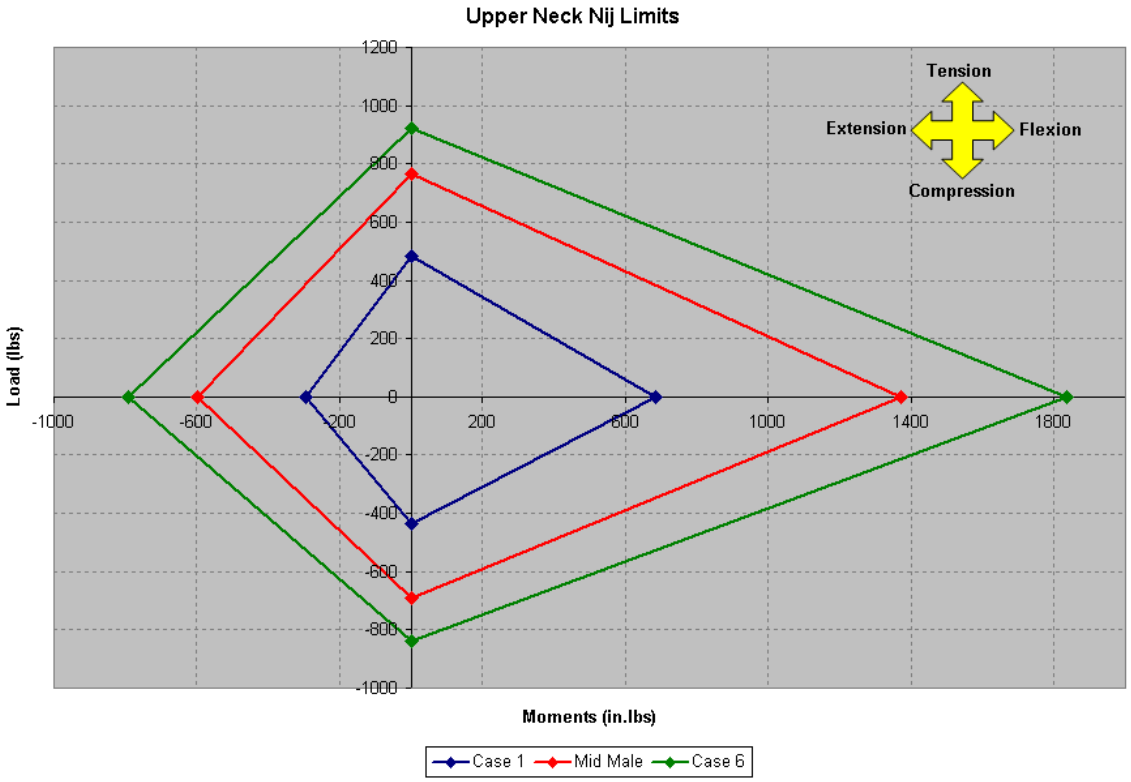
Issue 1- NIC Limits above 450 KEAS



2003 Neck Load Requirements

Issue 1- NIC Limits above 450 KEAS

- Difference in neck load limits between case 6 and smaller aircrew is more pronounced when axial loads are combined with the flexion / extension moments as part of the Nij injury criteria
- While the axial load limit difference between case 1 and case 6 is double, the moments limits are almost triple



Case 6 limits present a high risk of major neck injury to smaller aircrew

2003 Neck Load Requirements

Issue 1- NIC Limits above 450 KEAS

Issue 1 Summary

- For ejection safety and a reduced risk of a major neck injury, neck loading limits should extend to 600 KEAS for all aircrew and not degrade to case 6 limits above 450 KEAS

2003 Neck Load Requirements

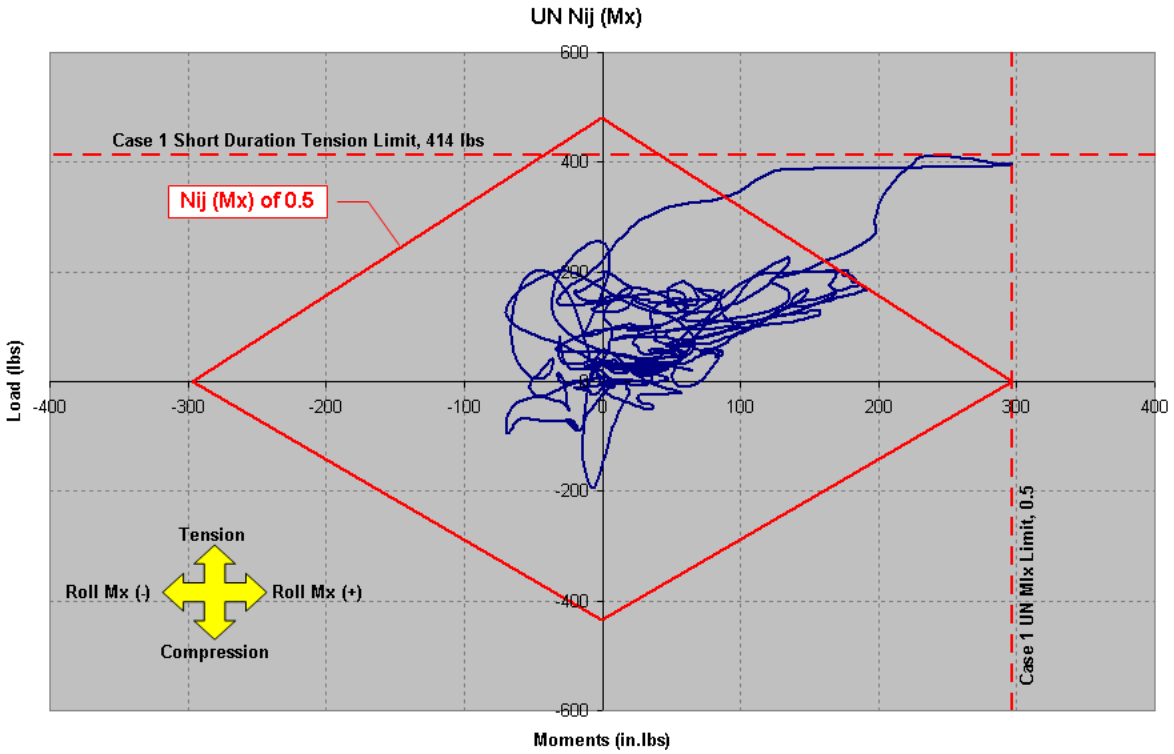
Issue 2- Out of Position

- **The out of position (OOP) condition is not adequately covered in the 2003 requirements**
  - **There is no reduction in axial load limits for the head / neck misaligned relative to the spine with Mx or Mz moments, e.g. head displaced to the side and interacting with a head restraint system**
  - **On seats with head restraint systems an OOP condition has the potential for much higher off axis Mx & Mz moments than with legacy seats**
  - **With the Nij criteria, axial load (Fz) limits are reduced with increasing flexion and extension (My) moments**
  - **There is no equivalent injury criteria for neck tension and off-axis moments, Mx & Mz, but the same principal does apply, i.e. if the neck is not aligned with the spine then its ability to withstand tensile and compression loads is reduced**

2003 Neck Load Requirements

Issue 2- Out of Position

- **In the example opposite*, where lateral roll moments (UN Mx) are plotted against axial loads (UN Fz), the measured loads do not exceed the current 2003 neck injury criteria, i.e. it is below the short duration tension limit and the UN MIx limit**
- **If an Nij type injury criteria were to be used with the UN My moments replaced with the UN Mx roll moments, then the load in this example would clearly exceed an Nij (Mx) of 0.5**



* Note: Data scaled from a real test to illustrate issue

2003 Neck Load Requirements

Issue 2- Out of Position

- **In another study from the automotive industry, related to neck loads from side impact air bags, it was proposed to use a modified Nij criteria which combines the Mx & My moments (Ref 1) as both together reduce the ability of the neck to withstand tensile loads**

$$\text{Modified } N_{ij} = \frac{F_z}{\text{Critical Tension}} + \frac{\sqrt{(M_y^2 + M_x^2)}}{\text{Critical Bending}}$$

- **For an improved ejection neck load requirement that would reduce the risk of neck injury it is proposed to combine all the moments in a modified Nij criteria, while maintaining the current limit of 0.5 for the upper neck**

$$\text{Modified } N_{ij} = \frac{F_z}{\text{Critical Axial Load}} + \frac{\sqrt{(M_y^2 + M_x^2 + M_z^2)}}{\text{Critical Bending}}$$

- **For the lower neck the modified Nij limit should be 1.0 as the current lower neck Mlz limit is 1.0**

Ref 1: SM Duma, JR Crandall, WD Pilkey, K Seki and T Akoi. Dynamic Response of the Hybrid III three year old dummy head and neck during side air bag loading. Proceedings of the Institution of Mechanical Engineers, Journal of Automobile Engineering, Volume 213, part D, 1999.

2003 Neck Load Requirements

Issue 2- Out of Position

Issue 2 Summary

- For ejection safety an Nij type injury criteria should be applied that includes the off axis moments that
  - Addresses the injury risk that was missed in the original 2003 requirements associated with the combination of axial loads and off axis moments
  - Further reduces the injury risk to all aircrew
- An injury criteria that addresses both of these points would be the modified Nij criteria with a limit of 0.5 for the upper neck and 1.0 for the lower neck

$$\text{Modified } N_{ij} = \frac{F_z}{\text{Critical Axial Load}} + \frac{\sqrt{(M_y^2 + M_x^2 + M_z^2)}}{\text{Critical Bending}}$$

2003 Neck Load Requirements

New Research

- In the area of neck injury there is always a significant amount of research and testing going on looking at injuries and new injury limits in the automotive world as well as in the military world
- Some of this research and testing may establish a better definition of neck load limits in some of the areas where there was no automotive background and no injury basis in the 2003 requirements
- An example of recent research is covered in the following slides that would highlight areas where the current 2003 requirements are in question

2003 Neck Load Requirements

New Research

- One area of research currently in progress with the Federal Aviation Administration (FAA) is looking at developing a side impact neck injury criteria
- They have already noted a lower tolerance to tensile loads when there is an applied lateral bending moment, Ref 1
- This would support the issues already covered associated with off axis moments and the need for a new criteria to adequately cover an acceptable risk of neck injury

Ref 1: Joseph Pellettiere, Richard DeWeeese and Allan Abramowitz. Side Facing Aircraft Seat Research Summary. Federal Aviation Administration.

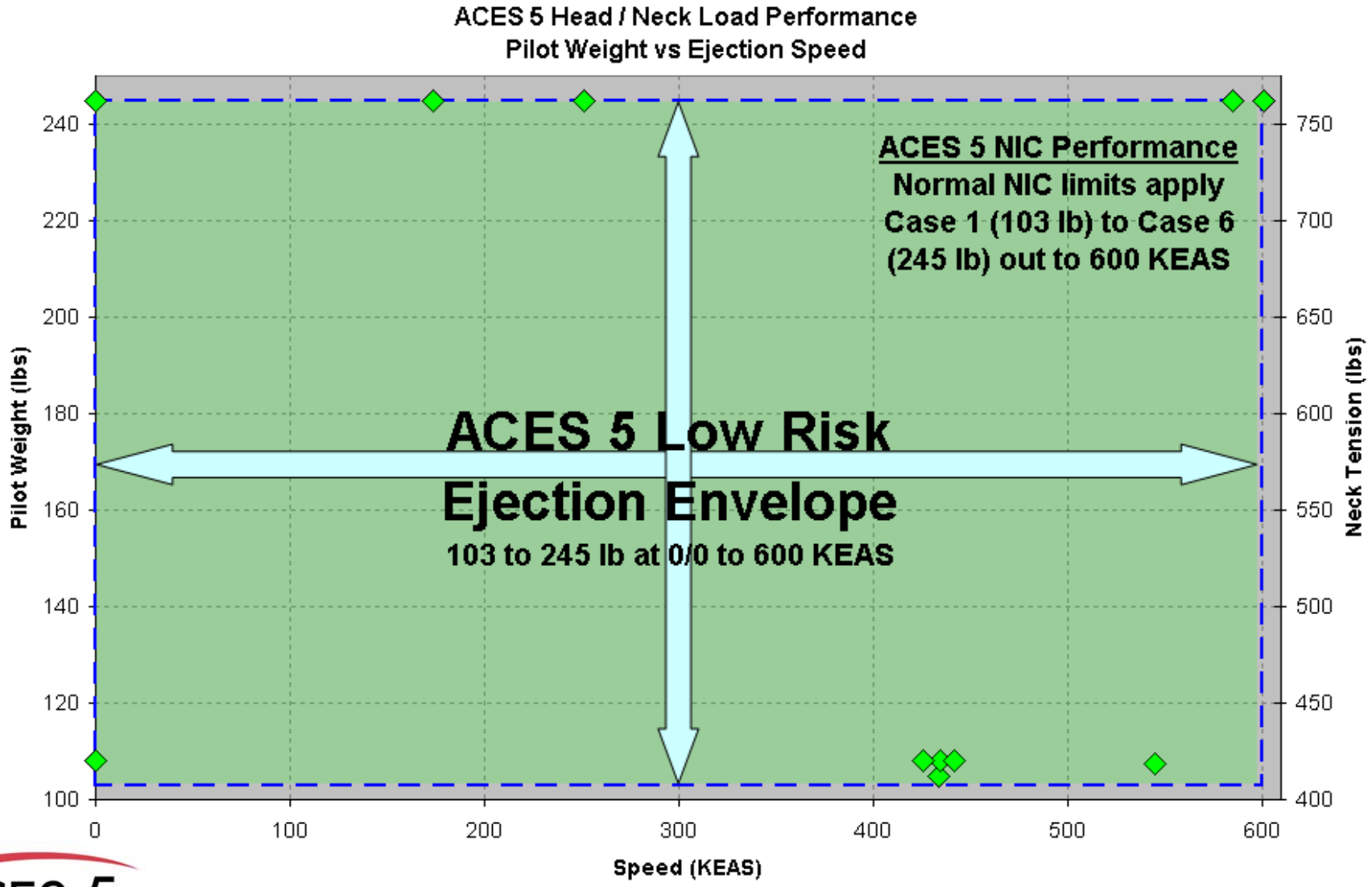
Improved Neck Load Requirements

- Neck load limits applicable out to 600 KEAS for all aircrew sizes and weights
- Apply the modified Nij injury criteria with a limit of 0.5 for the upper neck and 1.0 for the lower neck to replace the current Nij, MIx & MIz injury criteria

$$\text{Modified } N_{ij} = \frac{F_z}{\text{Critical Axial Load}} + \frac{\sqrt{(M_y^2 + M_x^2 + M_z^2)}}{\text{Critical Bending}}$$

Significantly reduced risk of neck injury for all aircrew at all ejection speeds

ACES 5 – Raising the Bar for Ejection Safety
Head / Neck Loading Performance



ACES 5
STAYING ALIVE ON ACES 5

ACES 5 – Raising the Bar for Ejection Safety

ACES 5 is the only seat that improves ejection safety over legacy seats and reduces the risk of injury to all aircrew at all ejection speeds

ACES 5 – Raising the Bar for Ejection Safety
Head / Neck Loading