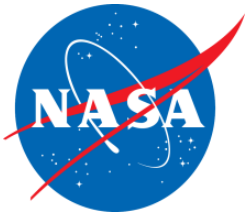


# ***Shoulder Injuries in US Astronauts Related to EVA Suit Design***

Rick Scheuring, DO, MS, FAsMA, FAAFP

Team Lead, Musculoskeletal/Sports Medicine and  
Rehabilitation NASA-Johnson Space Center

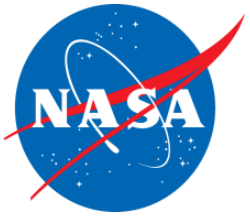
Fight Surgeon



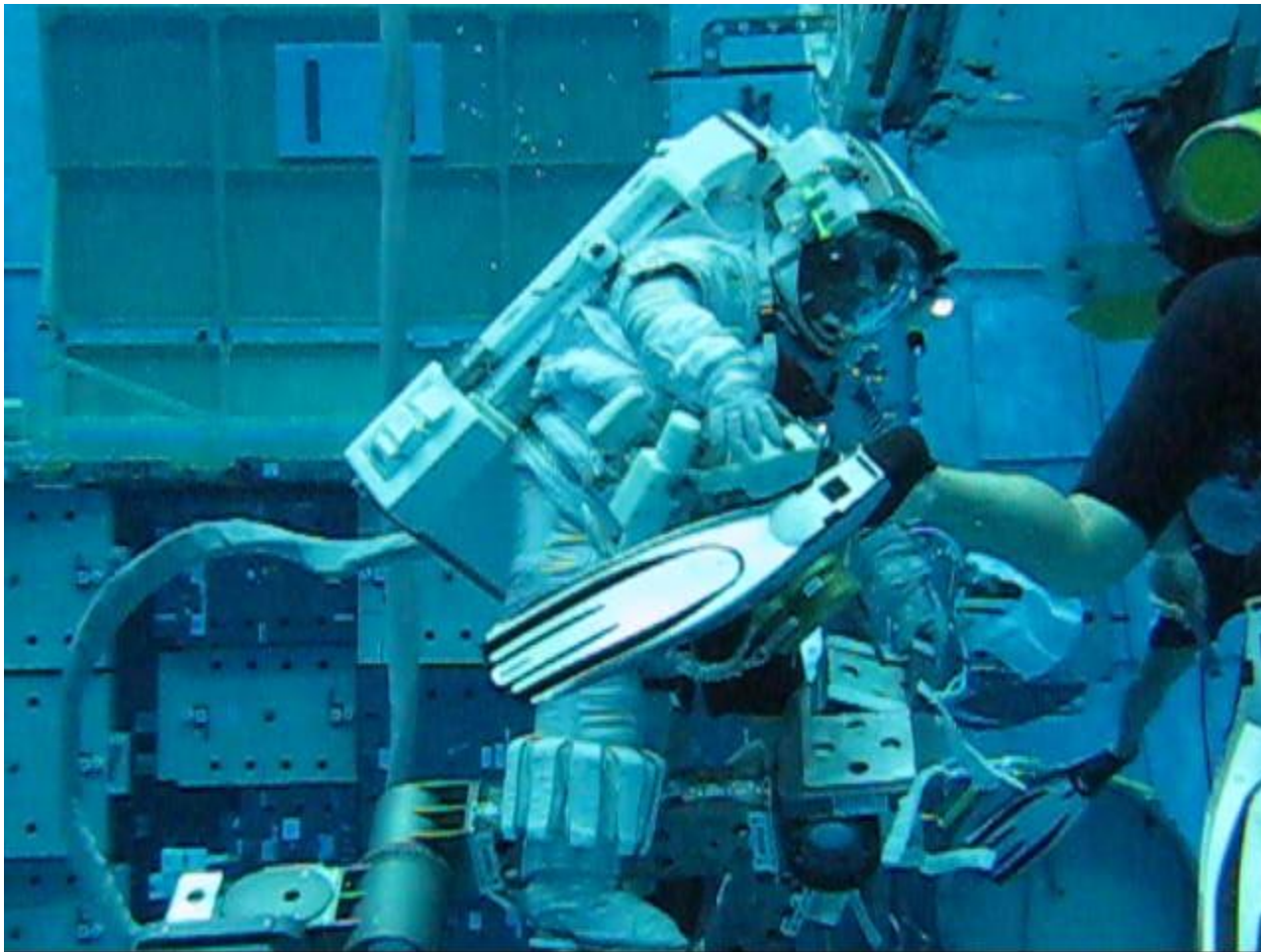
# Co-Authors

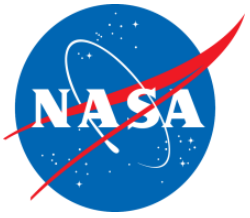
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- Pat McCulloch, MD- The Methodist Hospital (Houston) Orthopedic Surgery Dept
- Mary Van Baalen- Lead LSAH, NASA-JSC
- Charles Minard, Ph.D- Statistician, Wyle Labs
- Richard Watson- EVA Suit Engineering, NASA
- Steve Bowen- Astronaut, NASA-JSC
- Terri Blatt- MSK/Sports Med Project Manager



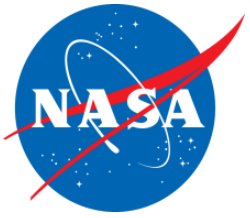
# Introduction





# NBL EVA Training

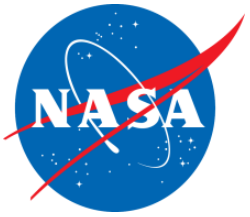
- Each training run is approximately 6 hrs in duration
- Training EVA: Spaceflight EVA ~6-10:1
- Suit pressurized to 4.3 psi/100% O<sub>2</sub>
- The goal of our study was to obtain objective data to support subjective or anecdotal reports



# Background

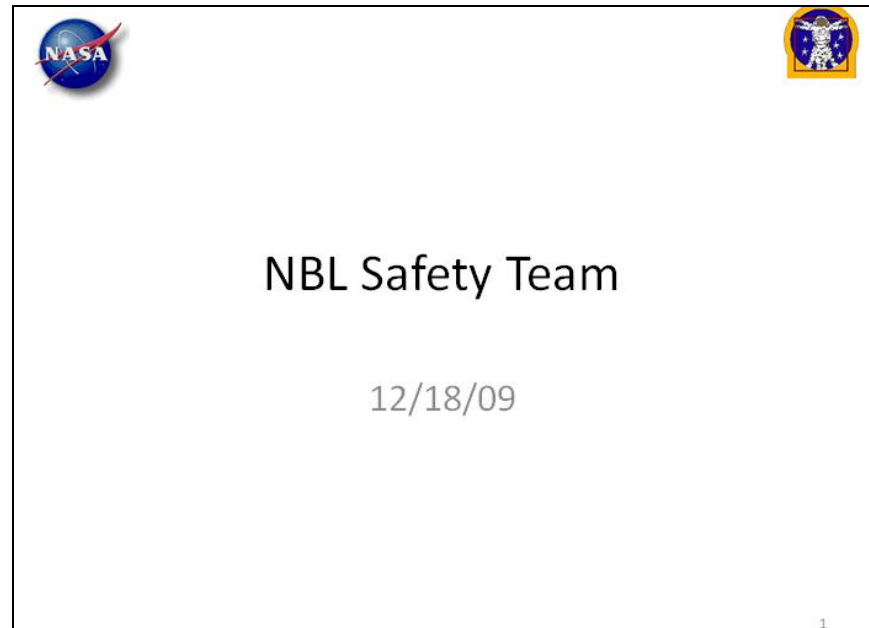
- 2003 NASA EMU Shoulder Injury Tiger Team Report<sup>1</sup>
- “Major” shoulder injuries occur secondary to
  - Limitations to normal shoulder mechanics in the planar HUT
  - Inverted body positions
  - Performing overhead tasks
  - Use of heavy tools
  - Repetitive motions
  - Frequent NBL runs

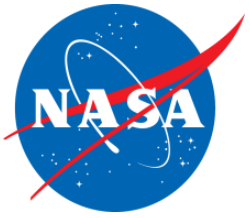
<sup>1</sup>Williams DR, Johnson BJ. EMU Shoulder Injury Tiger Team Report. NASA/TM-2003-212058, Sept. 2003.



# Background

- Shoulder injury mishap occurred during suited NBL training
  - crewmember experienced a shoulder strain during an NBL run
  - related to wearing a stainless steel waist bearing in place of the standard aluminum waist bearing

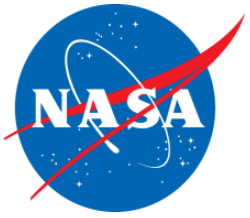




# Background

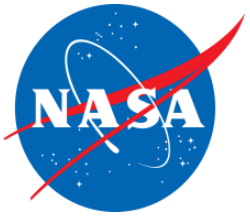
## Issues addressed in the NBL Safety report

1. Are there a lot of astronaut injuries at the NBL?
2. Are there injuries and close calls at the NBL that go unreported and undocumented?
3. Have we normalized the signs of an impending injury due to the inherent issues with the suit design and the NBL environment? That is, have we just accepted the hazards associated the suit design and the NBL environment.
4. Are the NBL injuries preventable?
5. Does the use of EMU stainless steel waist rings vs. aluminum waist rings cause injuries in the NBL?
6. Are the configuration control and configuration change processes allowing unapproved EMU and Tool configurations to be used in the NBL?
7. Is medical care at the NBL “state of the art” especially in the area of preventative measures?
8. **Is the EMU planar shoulder design the root cause of most of the NBL shoulder injuries?**
9. Are heavy tools (not neutrally buoyant) a contributing factor to shoulder injuries in the NBL?



# Background

- Current NBL Safety team assessed the implementation status of all the recommendations from 2003 Shoulder Injury Tiger Team report
  - *“All actions and recommendations were implemented effectively and have had positive results with respect to safety at the NBL”*
  - Key Items not implemented:
    1. EMU Planar Shoulder not redesigned
    2. Limited tracking of crew physical training due to multiplicity of training venues

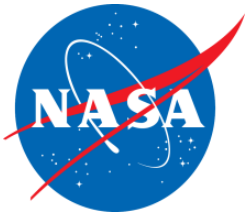


# NBL/EMU-Related Shoulder Injury

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- Planar HUT when compared to the Pivoted
  - Restricts range of shoulder motion, placing increased strain on the rotator cuff muscles
  - Fixes the shoulder in internal rotation predisposing the shoulder to impingement
- The injuries sustained are chronic, cumulative and in time, many cases require surgery

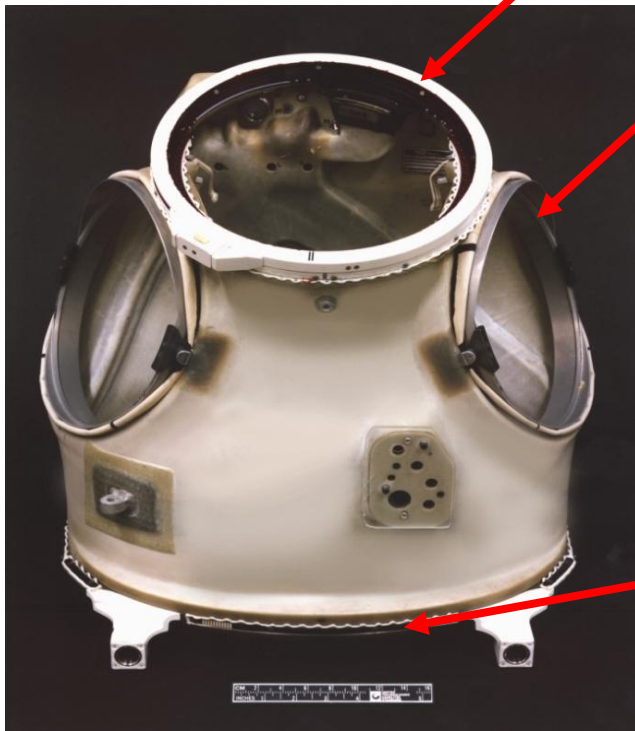


# Pivoted vs. Planar HUT

Helmet Disconnect – Same Size

Scye Openings  
Pivoted – 2 Sizes  
Planar – 1 Size

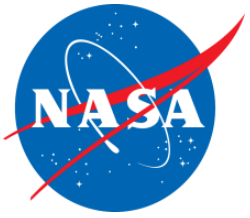
HUT Side BSC  
Pivoted – 3 Sizes  
Planar – 1 Size



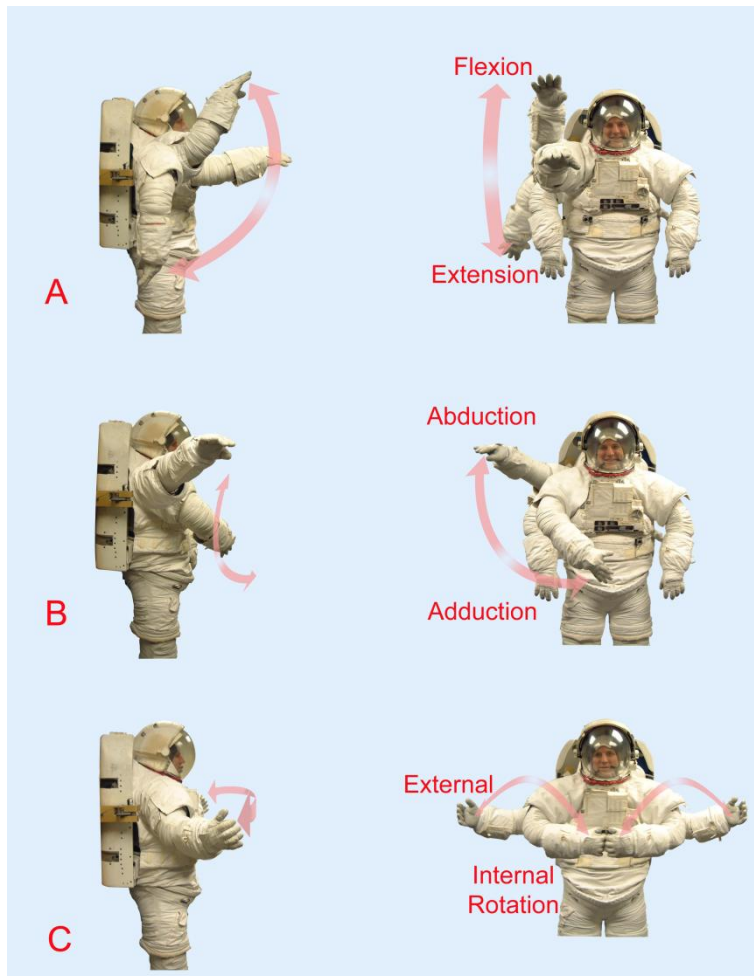
**Pivoted HUT**



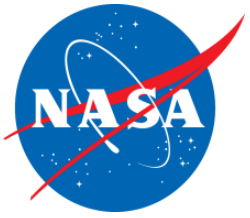
**Planar HUT**



# Suited Shoulder ROM

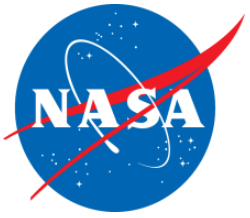


- Planar HUT design limitations in shoulder ROM
  - Abduction  $\sim 60^{\circ}$ - $90^{\circ}$
  - Flexion  $\sim 90^{\circ}$
  - Internal rotation  $\sim 40^{\circ}$
  - External rotation  $\sim 35^{\circ}$



# Shoulder Range of Motion (ROM) Pivoted vs. Planar HUT



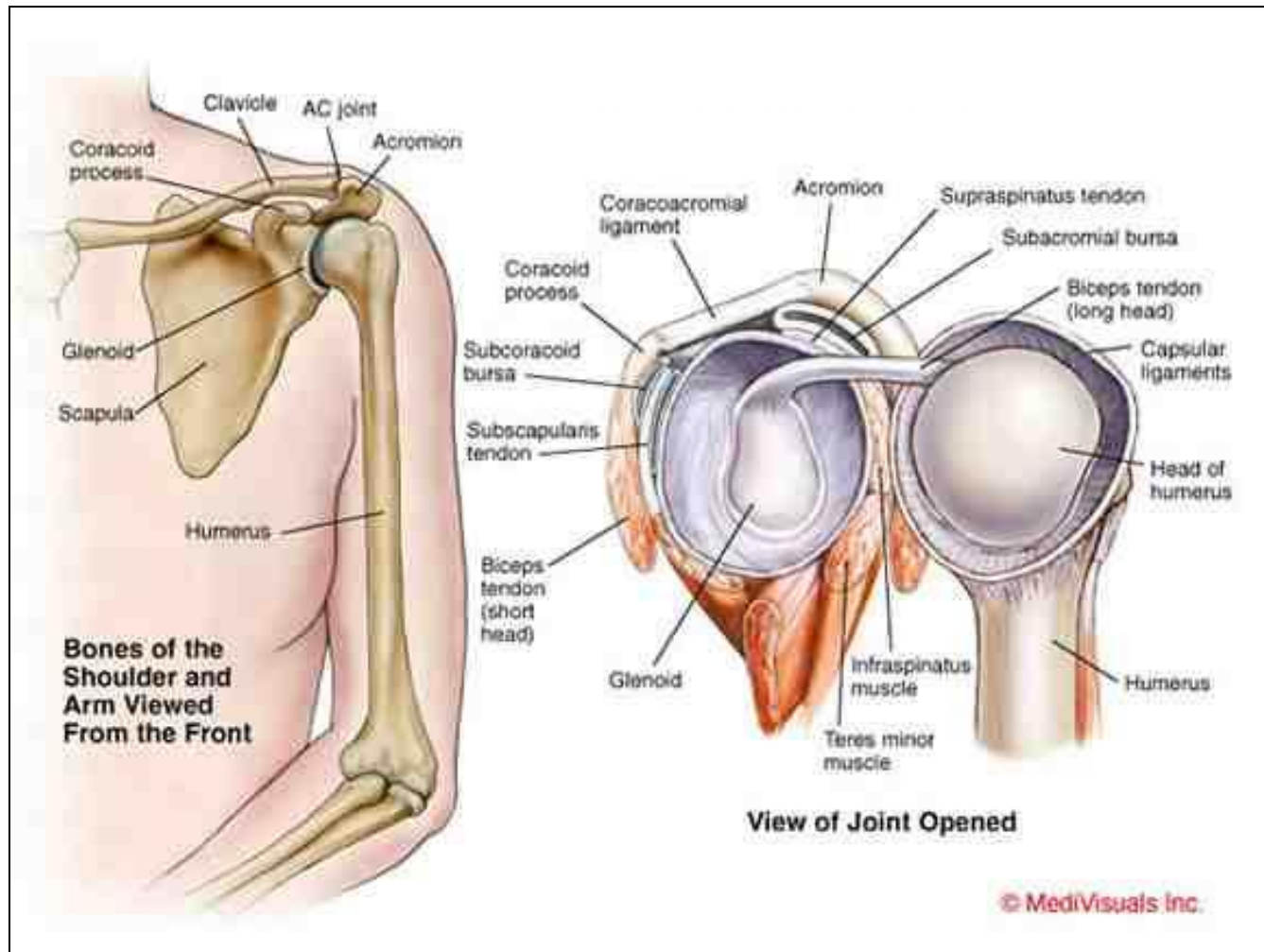


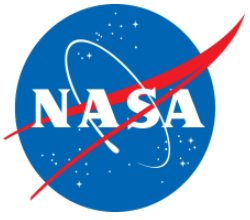
# Suit Donning and Doffing



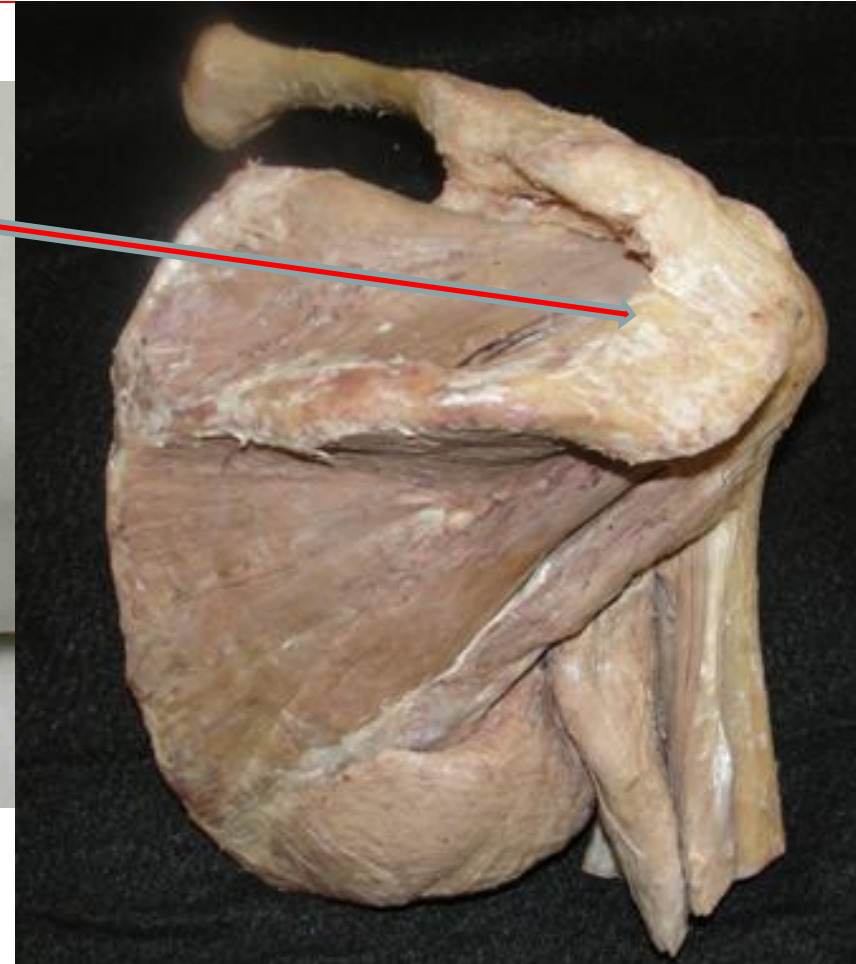
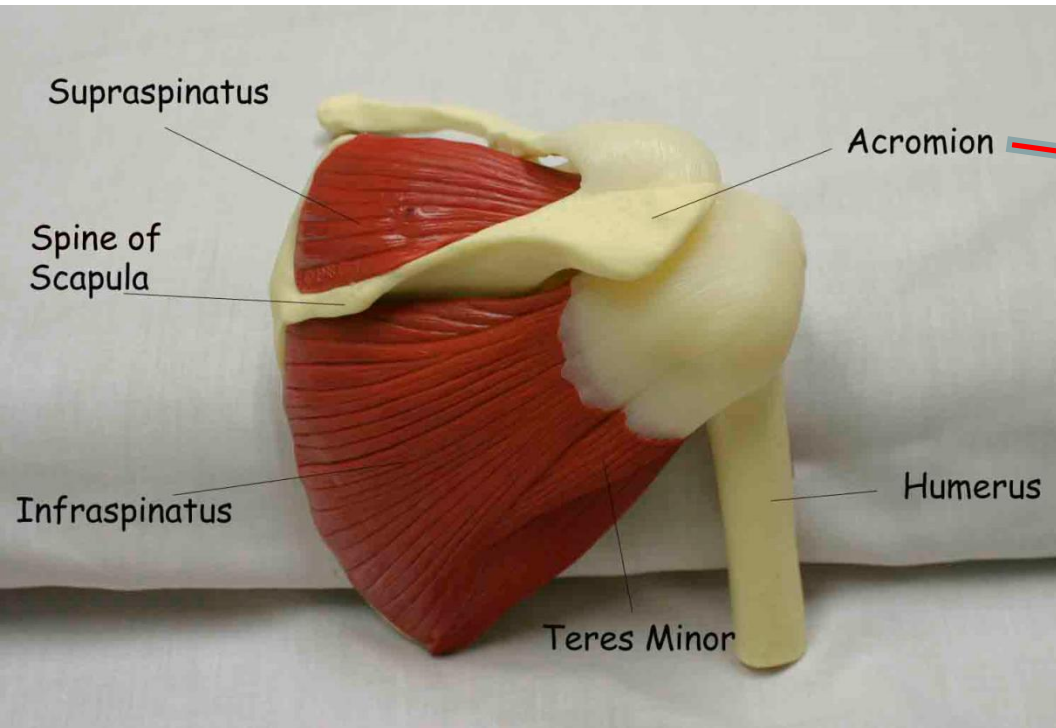
Williams DR, Johnson BJ. EMU Shoulder Injury Tiger Team Report. NASA/TM-2003-212058, Sept. 2003.

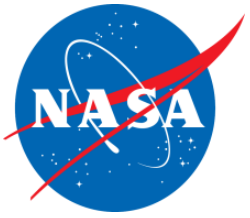
# Shoulder Anatomy





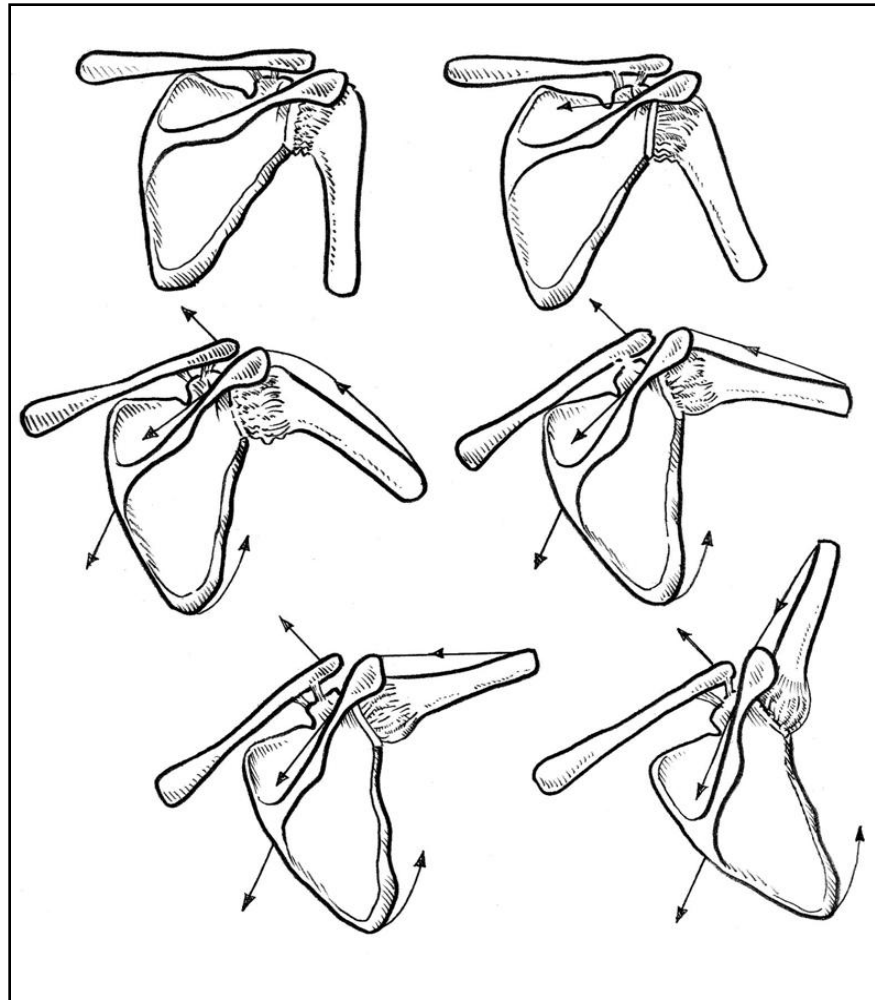
# Rotator Cuff Anatomy

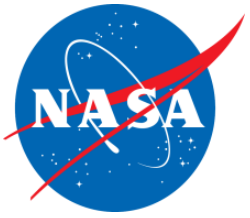




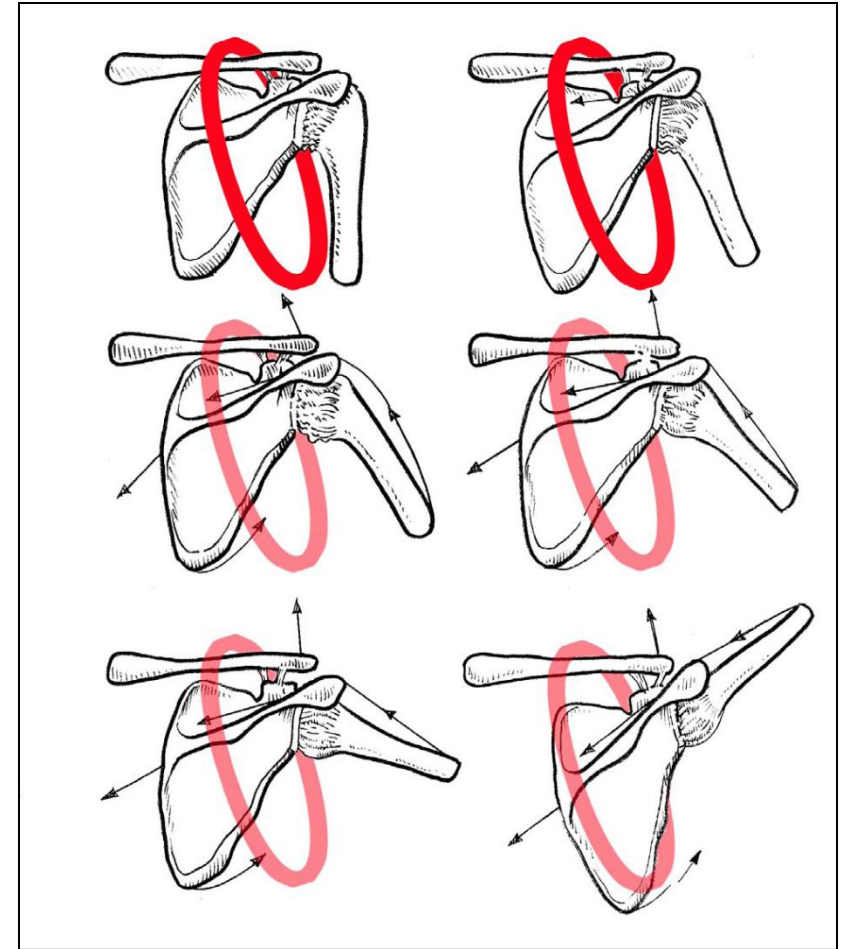
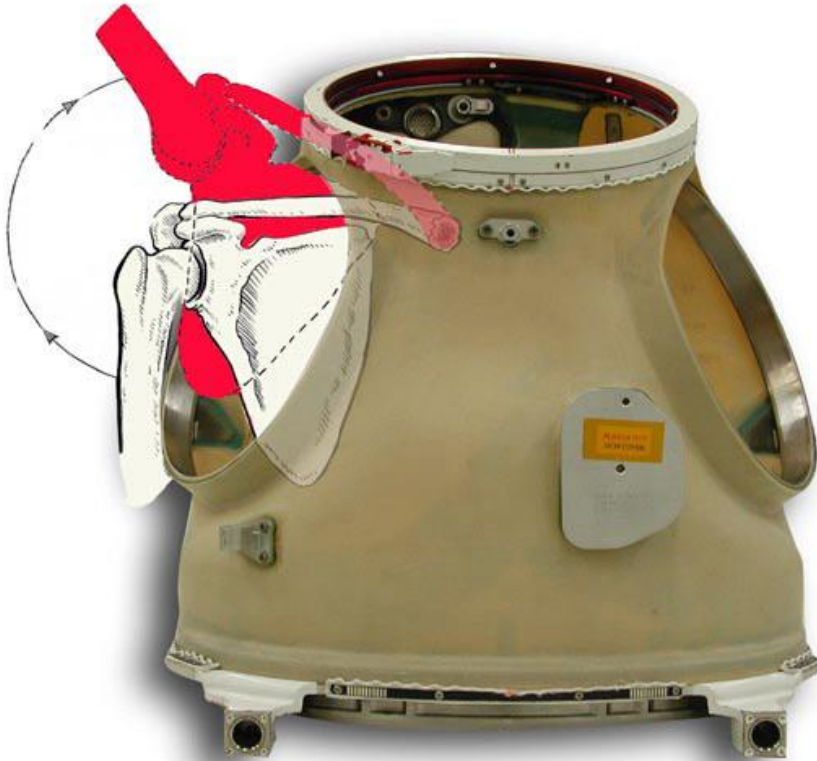
# Shoulder Range of Motion

Right  
Shoulder  
Viewed from  
Behind

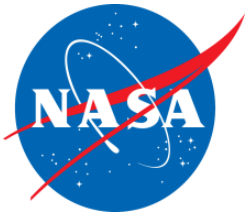




# Scye bearing joint restricting shoulder movement<sup>1</sup>



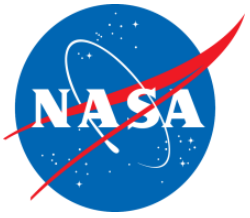
<sup>1</sup>Williams DR, Johnson BJ. EMU Shoulder Injury Tiger Team Report. NASA/TM-2003-212058, Sept. 2003.



# LCG Skin Impressions Following 6 hr NBL Run



<sup>1</sup>Williams DR, Johnson BJ. EMU Shoulder Injury Tiger Team Report. NASA/TM-2003-212058, Sept. 2003.

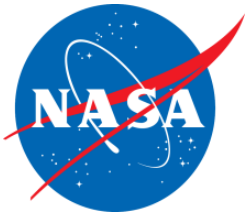


# Shoulder clearance relative to the Scye bearing

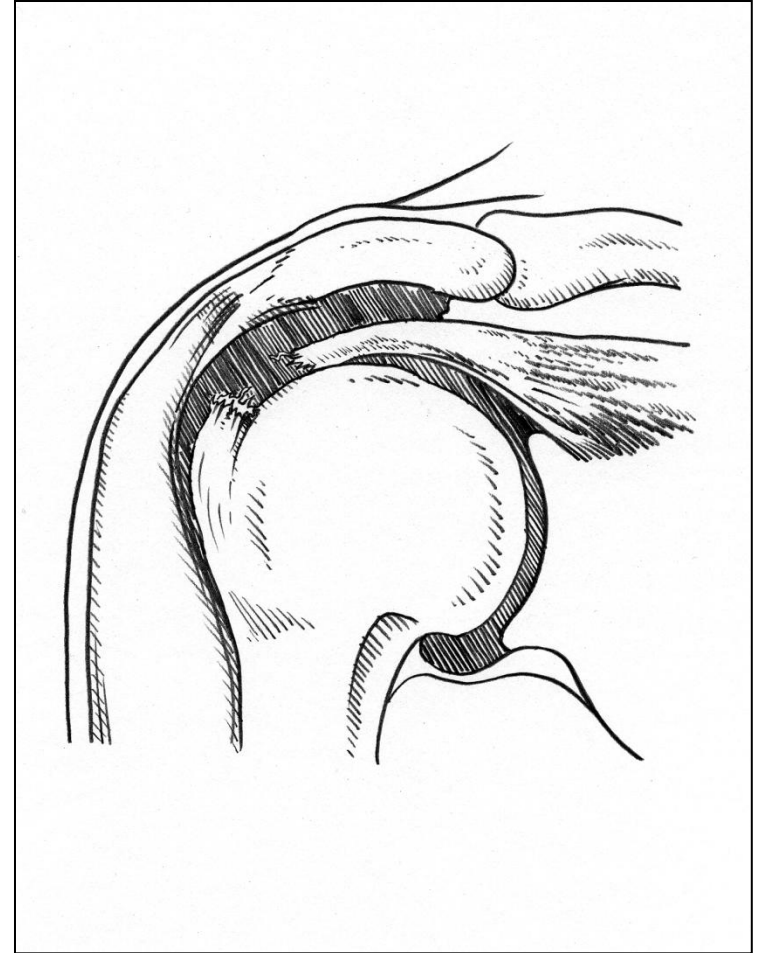


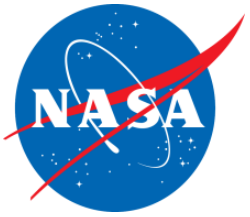
**Figure 3-10 Superior shoulder irritation within 24 hours after an NBL run.**

<sup>1</sup>Williams DR, Johnson BJ. EMU Shoulder Injury Tiger Team Report. NASA/TM-2003-212058, Sept. 2003.

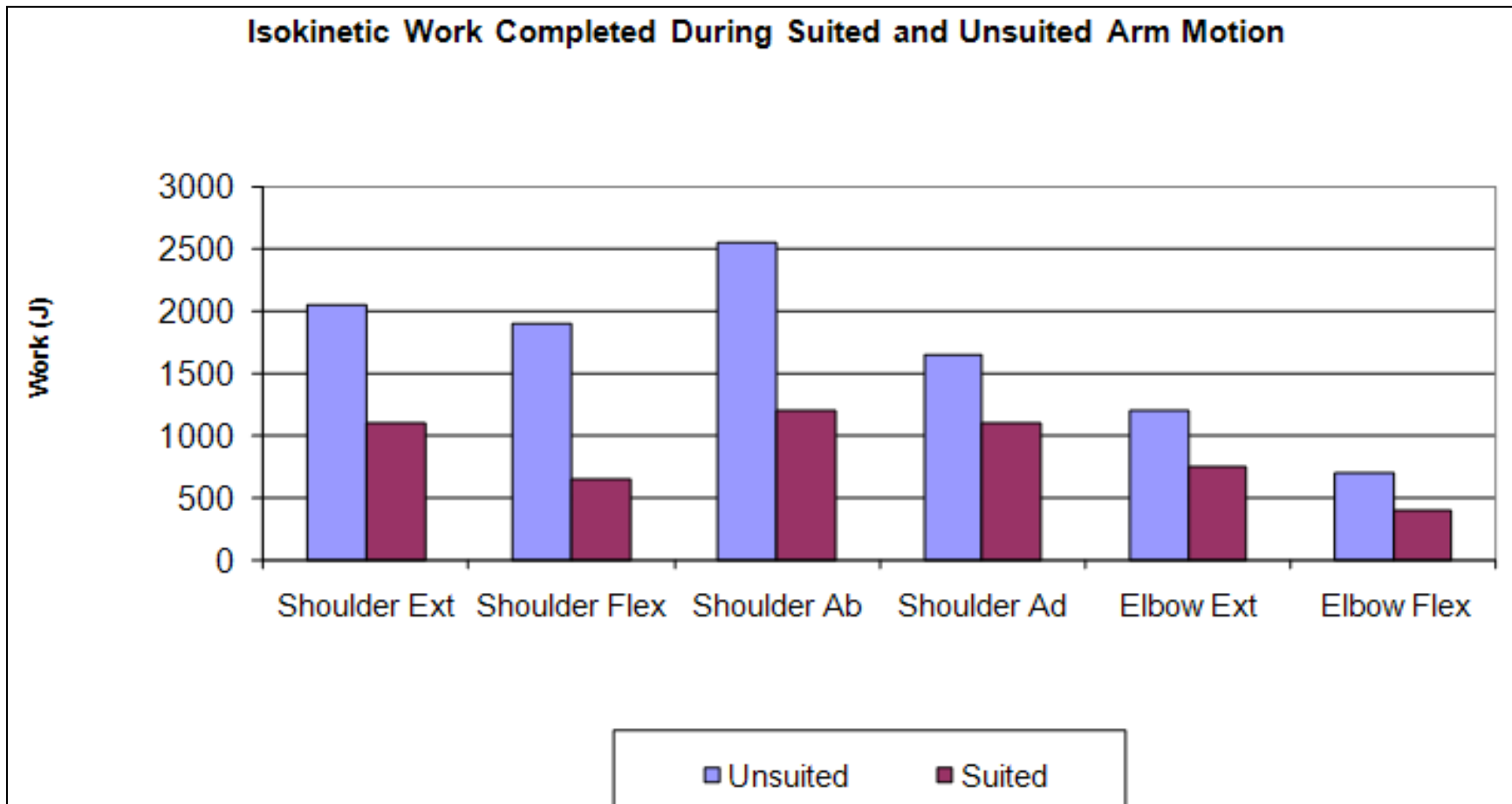


# Shoulder Impingement & Rotator Cuff Tear

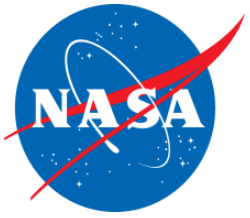




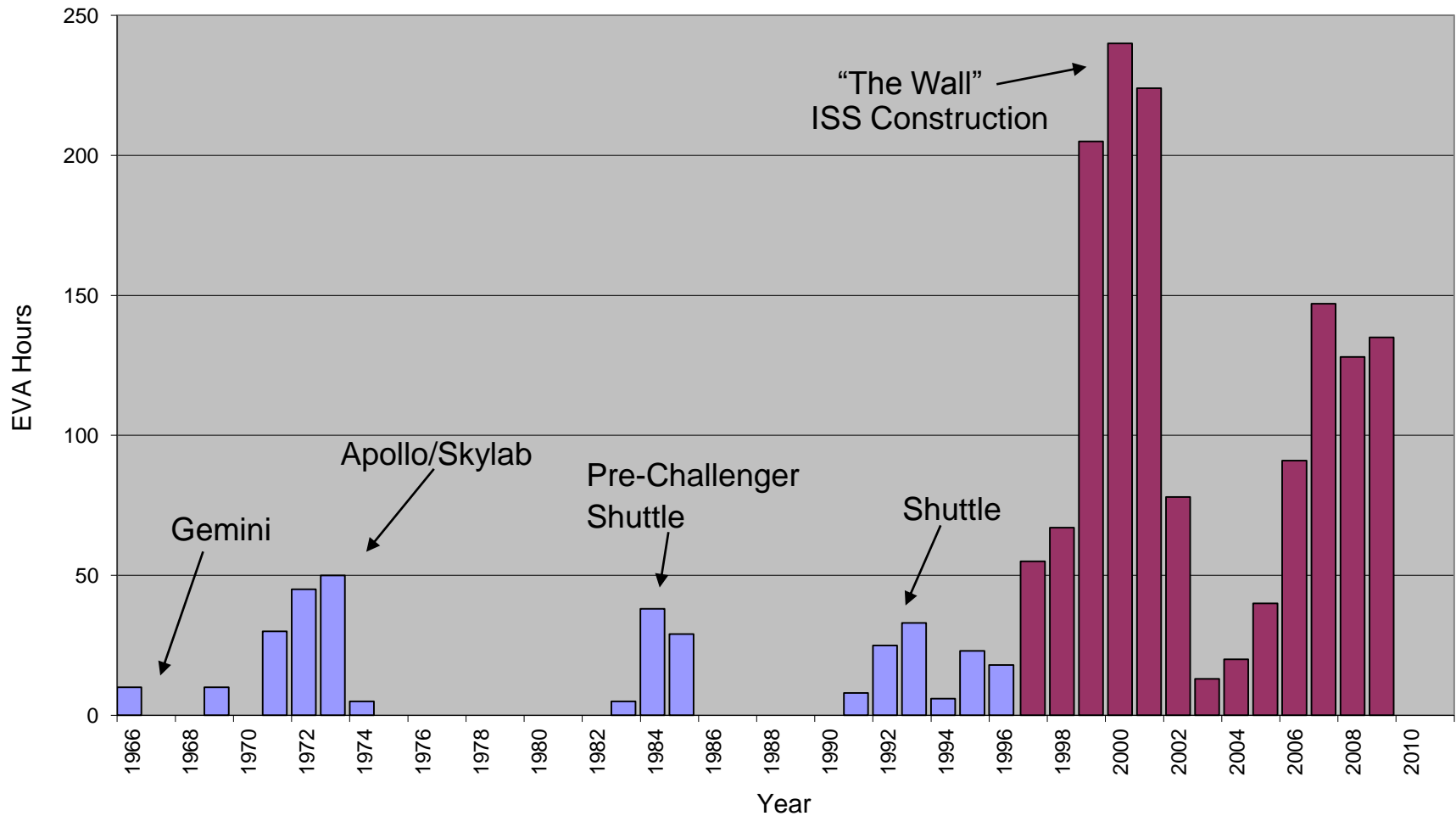
## Un-suited vs. suited (planar HUT) shoulder strength related to normal scapulo-thoracic mechanics\*

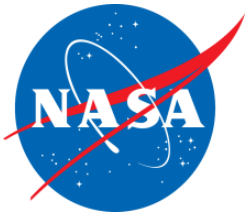


\*Data used with permission from M. Guilliams, S. Rajulu 2011.



# Study Assumptions

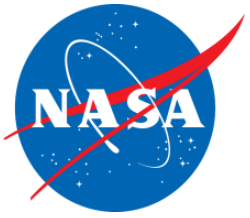




# Methods

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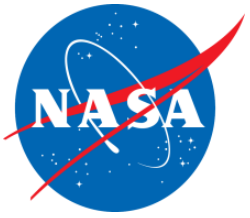
- US astronaut EVA training data and spacesuit design employed were analyzed from the NBL database from 1995-2011.
  - Shoulder surgery data was acquired from the medical record database
  - causal mechanisms were obtained from personal interviews
  - analysis of the individual HUT designs was performed as it related to normal shoulder biomechanics



# Shoulder Injuries Requiring Surgical Repair



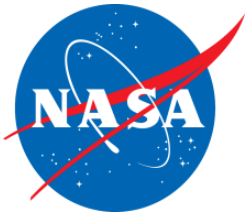
- 330 US astronauts
  - 103 have performed at least one space flight EVA (prior to shoulder surgery)
- 23 astronauts have had shoulder surgery
  - 25 surgeries
  - two astronauts have had surgery on both shoulders
- Excludes shoulder ***injuries***
  - Including prior history of training-related shoulder surgery
  - Sprains and strains
  - Impingement
  - Pain



# Shoulder Surgeries

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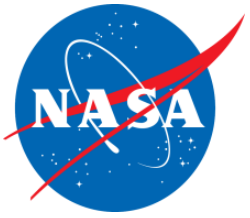
- Of the 25 astronauts who have had surgery
  - 12 describe an event or mechanism of injury related to training in the planar HUT
  - 12 deny any specific event that can be attributed to donning, doffing or training in the EMU
  - 1 remain outstanding or unknown as of 12-Apr-12



# Individual Shoulder Surgery Cases



Surgery Related to EMU Suit <sup>†</sup>	#	Planar HUT Only	Pivoted HUT Only	Both Planar and Pivoted HUT	No EMU Suit Exposure	Surgical Diagnosis (but no procedure)
YES	10 <sup>‡</sup>	2	0	8*	0	2 (Planar)
NO	12	1	6	4	1	0
UNKNOWN	2**		3			
<b>Total</b>	<b>24</b>	<b>3</b>	<b>9</b>	<b>12</b>	<b>1</b>	<b>2</b>
<sup>†</sup> Based on personal communications with individual crewmembers						
<sup>‡</sup> 5/9 crewmembers had their injury and subsequent shoulder surgery after 2004						
*7 crewmembers started in planar HUT but switched to pivoted following injury						
**One crewmember is deceased						

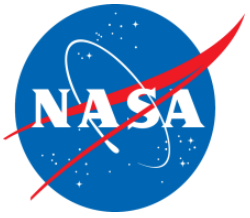


# Shoulder Surgery related to EVA Suit



Was surgery related to suit?	Pivoted Only	Planar Only	Both
Yes	0	2	7
No	6	1	4
Column %	0.0	66.7	63.6

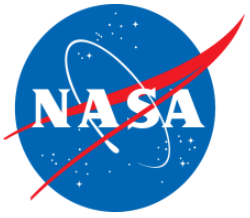
- $P = 0.03$
- The % of astronauts who attributed the shoulder surgery to the suit was significantly different across suit groups.



# Pivoted vs. Planar

Was surgery related to suit?	Pivoted Only	Planar Only
Yes	0	2
No	6	1
Column %	0%	66.7%

- $P = 0.08$  (Fisher's exact)
- Not significant assuming 0.05 level of significance, but it's *suggestive of a real difference*
  - We just have a very small sample size

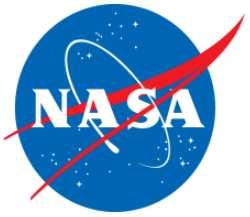


# Caveats to training data

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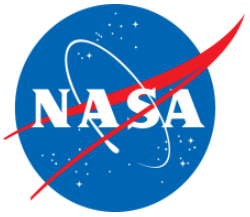


- After 1997, astronauts would train in the planar HUT until they got injured, then would switch to the pivoted HUT



# Initial Assessment

- Planar suits first used for *space flight* EVAs on STS-82
  - Only Shuttle data used
- EVAs pre STS-82 (<1997)
  - Pivoted suit
- EVAs post STS-82 (>1997)
  - Planar suit
- 88 astronauts with US space flight EVAs
  - Excludes Orlan only
  - Excludes non-Shuttle EVAs
  - Excludes EVAs post-surgery (first surgery)



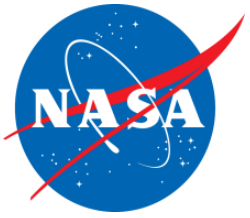
# Surgeries by Number of EVAs



Surgery	1	2-4	$\geq 5$	Total
No	16	43	21	80
Yes	1	4	3	8
Total	17	47	24	88
% Surgery	5.9	8.5	12.5	9.1

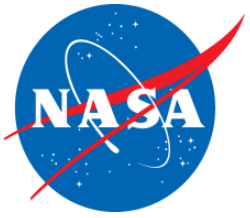
- $P = 0.78$  (Fisher's)
- $P = 0.59$  (Trend)

- Not statistically significant but a trend emerged
- Astronauts who performed  $\geq 5$  EVAs were 2.1 times more likely to have had shoulder surgery compared with astronauts who performed 1 EVA



# EVA Training Data

- Training data became available
  - June 1995 to present- electronic
    - NBL became functional in Oct. 1996
  - No data available for 176 astronauts
  - Older records in paper format are not included in this data set
- Clarification that training occurs in *both* suits for most astronauts
- Number of EVA training runs
  - Pivoted
  - Planar
  - Duration of training runs not included



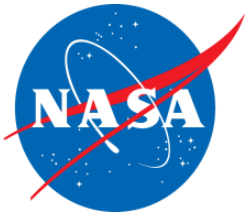
# Average Number of EVA Training Runs by Surgery and Type of Suit\*



Surgery	N	Pivoted Runs	Planar Runs	Total
No	143	14.7	36.3	51.0
Yes	11	25.9	59.2	85.1
Total	154	15.5	37.9	53.4

\*Review of training data indicates most astronauts participated in more runs in the planar HUT after 1997

\*Did not take into account the temporal relationship between suit type and injury occurrence



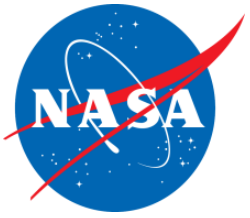
# Surgeries by Total Number of Training Runs (Quartiles)



	0-9	10-38	39-91	92-228	Total
No Surgery	36	38	37	32	143
Surgery	1	2	2	6	11
Total	37	40	39	38	154
% Surgery	2.7	5.0	5.1	15.8	7.1

- Fisher:  $P=0.20$
- Trend:  $P<0.05$

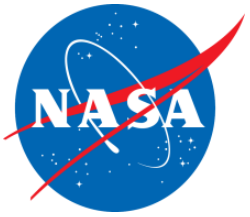
• Astronauts who had >92 total training runs (in either suit) were about 5.9 times more likely to have had shoulder surgery compared with astronauts who have had 0-9 training runs



# Planned EVAs in Future

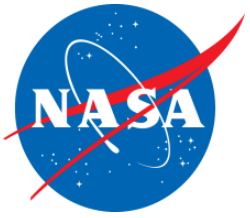
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- For ISS missions, ~8 EVAs planned per year
- Numbers of crew members limited
- CONUS training time for US crewmembers limited
  - i.e. training “density” may still be an issue secondary to international travel, other duties, etc



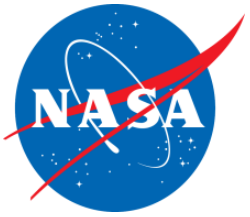
# Preliminary Summary

- For spaceflight EVA
  - Astronauts who performed  $\geq 5$  EVAs were 2.1 times more likely to have had shoulder surgery compared with astronauts who performed 1 EVA
- For training EVA
  - The proportions of astronauts who attribute their injury to the planar HUT was significantly different across the 3 groups (Pivoted vs. Planar vs. Both).
    - Astronauts who trained ONLY in the pivoted suit were less likely to attribute the injury to the pivoted HUT compared with astronauts who trained ONLY in the planar or in both suits.
  - Astronauts who had >92 total training runs (in either suit) were about 5.9 times more likely to have had shoulder surgery compared with astronauts who have had 0-9 training runs
    - Regardless of the HUT design, the likelihood of shoulder sx increased from 2.7% (0-9 runs) to 5% (10-91 runs) to 15.8% (>92 runs)



# Conclusions

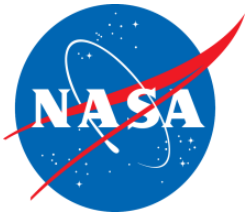
1. There are *multiple* factors associated with the mechanism of injury that leads to shoulder injury requiring surgical repair
  - E.g. Limitations to normal shoulder mechanics, suit fit, donning/doffing, body position, pre-existing injury, tool weight and configuration, age, in-suit activity, training density, etc.



# Conclusions

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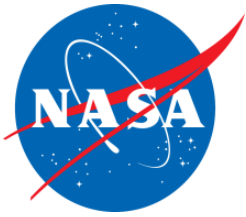
2. Despite the injury prevention measures taken from the 2003 Shoulder Tiger Team recommendations, shoulder injuries and subsequent shoulder surgeries remain relatively unchanged
  - 6/12 (50%) of astronauts who attributed their injury leading to surgery to training in the EMU occurred *after* 2004.



# Recommendations

1. Crewmembers with pre-existing or current shoulder injuries or certain anthropometric body types should conduct NBL EVA training in the pivoted HUT.
2. Individuals that have clinical symptoms consistent with shoulder injury associated with NBL EVA training may have alterations to training frequency at the discretion of the evaluating flight surgeon<sup>3</sup>.
3. Develop a training tracking method to electronically document astronaut NBL EMU runs, type of HUT, time in suit, occurrence of injury, whether ice was applied, etc.
4. Team up with shoulder specialists, EVA suit designers, astronauts and flight surgeons to study how proper shoulder biomechanics can be incorporated into existing design configurations, i.e. HUT design

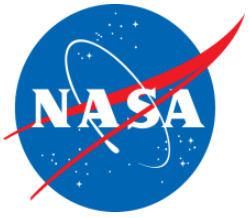
<sup>3</sup>Scheuring RA, Shaskan G, et al. Shoulder Medical Tiger Team Recommendations, March, 2010.



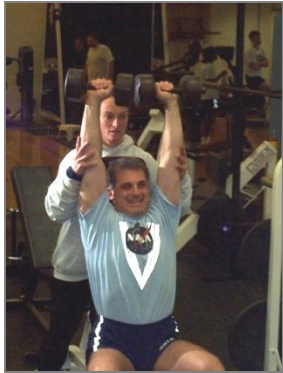
# Current EVA Shoulder Injury Prevention Program



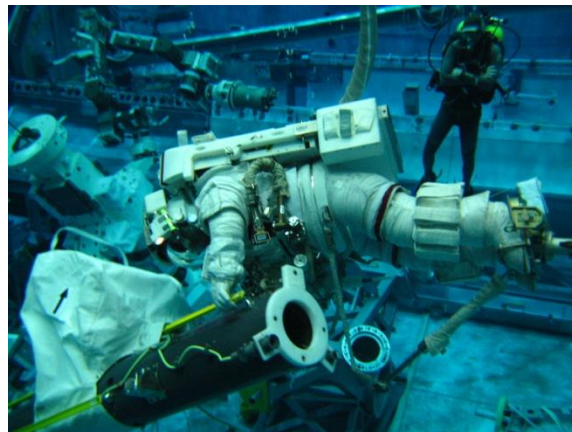
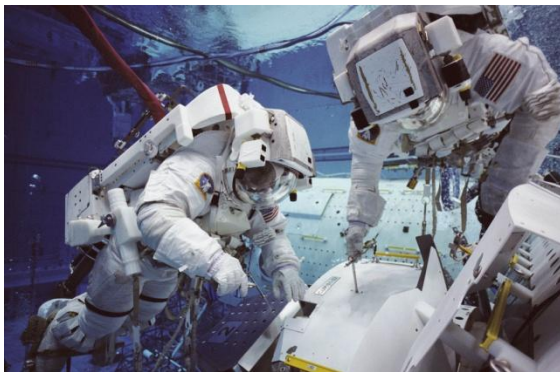
	EV1	EV2
Crewmember Last Name	Bagel	Cream Cheese
Time in the Pool (HH:MM)	06:07	06:07
Total Time Inverted (MM)	:00	:03
HUT Type (Pivoted or Planar)	Pivoted	Planar
Waist Bearing Type (Steel or Aluminum)	Aluminum	Aluminum
Shoulder Harness? (Yes/No)	No	Yes
Shoulder Pads? (Yes/No)	Yes	No
Teflon Inserts? (Yes/No)	No	No
Injury Reported? (Yes/No)	No	No
Shoulders Iced? (Right/Left/Both/Deferred)	Ice bilateral shoulder	Ice bilateral shoulder

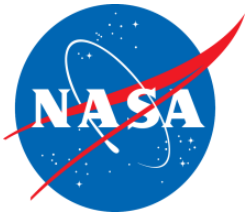


# EVA Fitness Program



- A well rounded exercise plan allows the crew to attain greater overall strength through **functional movement patterns**
- Prescribe multiple joint/multiple muscle exercise movements

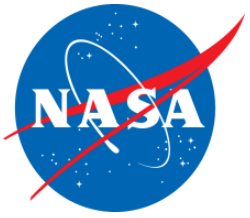




# EVA Fitness Program

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- Triple Extension & Lower Extremity Based Exercises – Squats, Deadlifts, RDL's, Hamstring Curls, Kettlebell Swings, etc.
- Pushing Exercises – Bench Press, Shoulder Press, Push-Ups, etc.
- Pulling Exercise – Cable Row, Lat Pulldown, Pull-Ups, etc.
- Accessory Exercises – Shoulder Rotator Cuff Maintenance Program, Wrist/Forearm Exercises

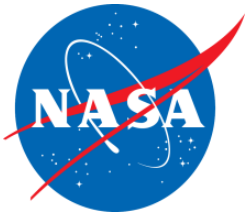


# Future Shoulder Injury Prevention Strategies

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- EVA Shoulder Fitness Evaluation, i.e. return to duty criteria
- Modify training time/density
- Optimize Pv HUT suit availability
- Identify individuals who have trained in PI HUT without injuries for anthropometric characteristics that may be “protective”



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