Understanding Spacesuit Glove Torques

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Generally speaking, all suit joints have a neutral position and resist deflection away from that position due to suit pressure acting on the specific joint geometry.

The plot below is of joint torque (bending resistance) for a continuous movement of the glove wrist joint from neutral to full adduction to neutral to full abduction then back to neutral. Starting at the X=0 point of the top curve and going clockwise around, we see torque rises with increasing angle of deflection. There is typically an increase in slope observed as the "soft limit" of the joint is approached. When the motion reverses (upper-right point) there is an initial rapid (vertical) drop as the resistive torque becomes assistive, then the torque (still resisting deflection from neutral) decreases then reverses near the neutral point, increasing again as the opposite joint soft limit is approached.

The separation between upper curve (going from max abduction to max adduction) and bottom curve (going from max. adduction to max. abduction) is representative of overall "frictional" effects (put in quotes because “frictional” is a composite of different effects: fabric bulk, sliding between layers, pivot friction, nonlinearities, etc.). The hysteresis loop shown in the plot is only apparent when recording loads while continuously moving the joint through full cycles. More space between upper and lower curves represents more of this frictional resistance to motion (in addition to pressure-induced resistance to deflection from neutral). A good analogy is moving your limb through a viscous fluid. When torque vs. deflection curves are measured statically at points along the deflection curve, the frictional effects of motion zero out and the hysteresis loop collapses into a single curve passing through 0,0 at the neutral position.

Phase VI 4.3 psid Wrist Adduction/Abduction

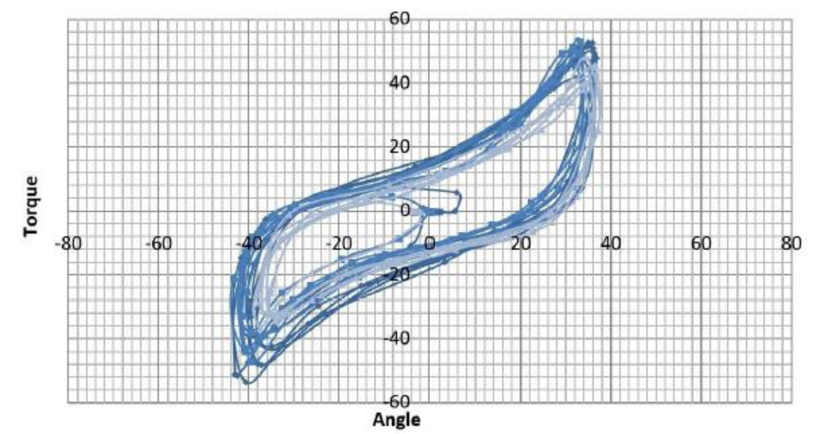
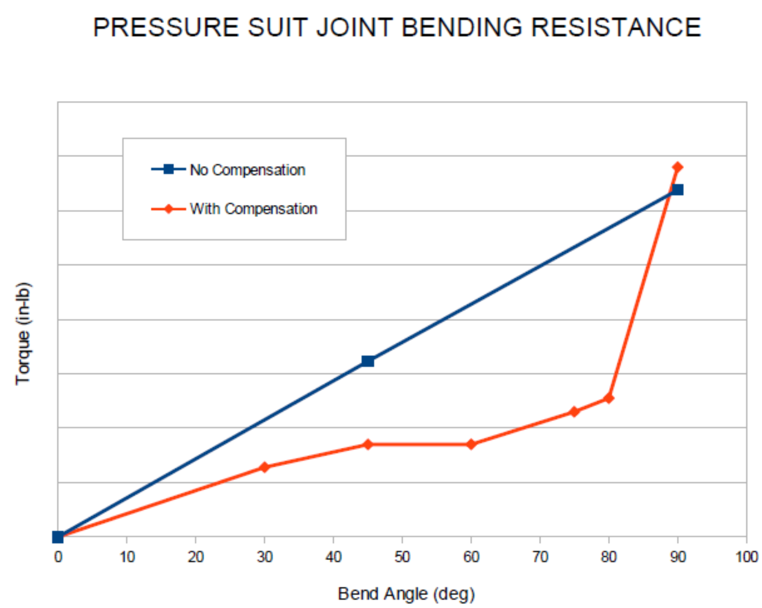


Figure 4. Torque profile for single axis joint. *Phase VI glove at 4.3 psid during wrist adduction/abduction.*

In general, the slope of the curve relates to the perceived stiffness or resistance to deflection caused by the pressure acting on the joint geometry. It represents a torque that increases with angular deflection from neutral, similar to a coil spring. An ideal joint would have a horizontal slope, that is no pressure torque at any angle. For any given joint, a lower slope angle represents a joint that is more flexible and less fatiguing.

The second plot is of (static) torque vs deflection of a suit test article to demonstrate the effects of "joint torque compensation" developed at Flagsuit. It is for a simple patterned convolute joint (single bending axis). The blue curve is a baseline that shows a linearly increasing bending resistance (torque) vs. deflection angle. The red curve is for the same simple convolute patterned joint but with pressure-assisted torque compensation added. The graph resembles the upper-right half of the previously shown torque plot (collapsed to a single curve, as the data was measured statically).



What's significant here? First, the slope of the orange curve is much lower than the blue baseline, meaning there is less pressure-induced resistance to joint deflection. Second, the lower resistance remains nearly constant almost all the way to the soft stop of the joint (around 80 degrees, which is quite high for a simple convolute joint). The palpable result is that the compensated joint is much easier to manipulate, not just initially but also throughout its range of motion.

The torque compensation (counter torque) is created by the suit's internal pressure. Therefore, it remains effective at all suit pressures making it feasible to operate suits at much higher pressure differential without degrading joint flexibility. A higher suit pressure with good joint flexibility has many operational benefits including shorter pre-breath, more frequent EVAs, and reduced risk of decompression sickness.

More can be read on spacesuit joint testing in the following two papers:

Matty, Jennifer. “Results and analysis from Space Suit Joint Torque Testing.” *40th International Conference on Environmental Systems*, 11 July 2010, https://doi.org/10.2514/6.2010-6211.

Valish, Dana, and Karina Eversley. “Space suit joint torque measurement method validation.” *42nd International Conference on Environmental Systems*, 15 July 2012, https://doi.org/10.2514/6.2012-3532.