ATHLETE Mobility Performance with Active Terrain Compliance

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ATHLETE Software Development Models (SDM)

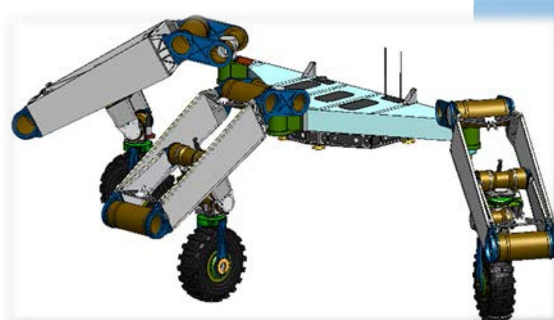
ATHLETE

1st Generation SDM (2005)

- 2 Units: SDM-A, SDM-B
- ¼ Lunar scale
- ~7 ft full height
- 6-DOF limbs with wheels

2nd Generation SDM (2009)

- 1 Unit: SDM-T12
  - Splits into two 3-limbed Tri-ATHLETEs and deployable cargo pallet
- ½ Lunar scale
- ~13 ft full height
- 7-DOF limbs with wheels



ATHLETE Mobility

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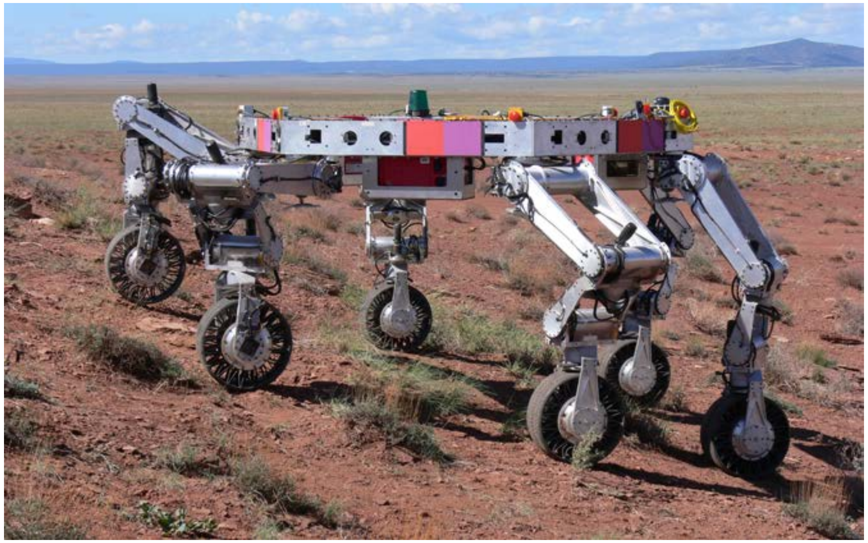
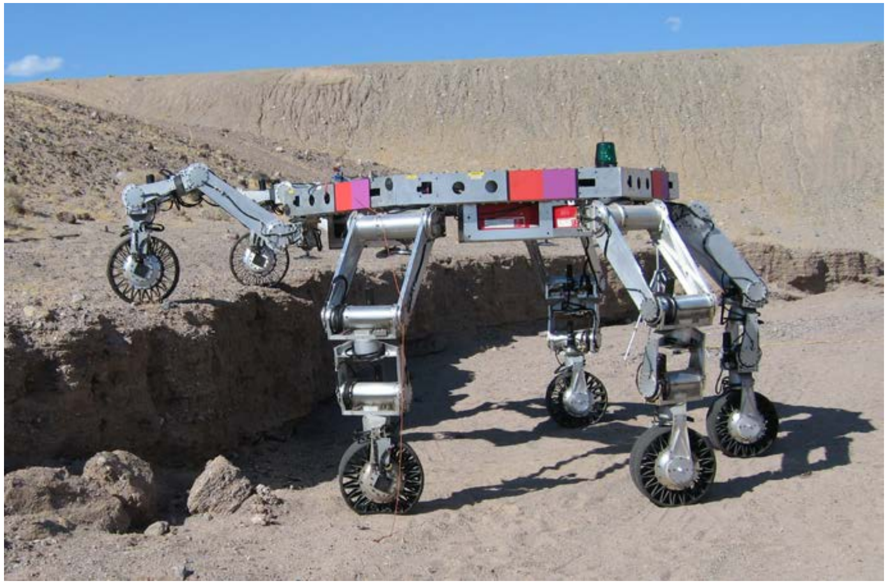
- Drive in benign terrain for speed and efficiency
- Walk in difficult terrain
- Minimal passive compliance





- Great capacity for complying to slopes and terrain when joints are actively controlled.

Active Terrain Compliance (1)

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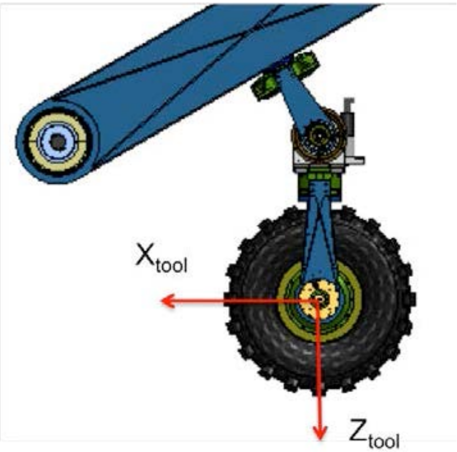
Multiple control objectives, calculated independently

- Force distribution
  - Compare Z_{tool} force estimates to ideal distribution
  - Extend/retract wheel along Z_{tool} axis to reduce deviation
  - For extreme deviation, reduce drive speed to accommodate limb adjustments
- Transverse Load Reduction
  - Terrain interactions lead to accumulated limb deflection
  - Detected as nonzero Y_{tool} force
  - Adjust steering to reduce limb deflection
- Wheel Speed Synchronization
  - Monitor for wheels lagging behind the commanded wheel rate profile
  - Retract wheel along Ztool axis to reduce loading
- Deck Leveling
  - Monitor IMU for tilt deviation
  - Extend/retract wheels along Z_{tool} axis to correct tilt
- Deck Centering
  - Adjust wheel positions along X_{tool} and Y_{tool} axes to center deck over footprint
- Deck Height Management
  - Extend/retract wheels along Z_{tool} axis to maintain desired deck height



Active Terrain Compliance (2)

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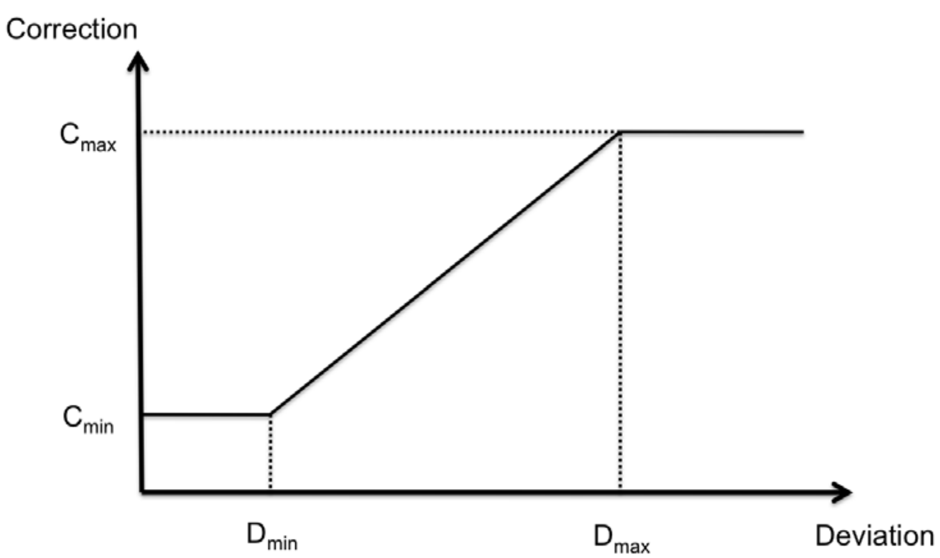
- Correction magnitudes selected via linear interpolation
  - $D \geq D_{max}$ gets maximum correction, $C = C_{max}$
  - $D \leq D_{min}$ gets minimum correction, $C = C_{min}$
  - $D_{min} < D < D_{max}$ gets interpolated correction $C_{min} < C < C_{max}$



Active Terrain Compliance (3)

- Correction components combined into an overall position and orientation goal.
- New goals applied at 2 Hz

$$
\begin{Bmatrix} x_{goal} \\ y_{goal} \\ z_{goal} \\ roll_{goal} \\ pitch_{goal} \\ yaw_{goal} \end{Bmatrix} = \begin{Bmatrix} x_{now} + x_{center} \\ y_{now} + y_{center} \\ z_{now} + z_{force} + z_{level} + z_{height} \\ 0 \\ 0 \\ yaw_{now} + yaw_{yload} \end{Bmatrix}
$$

Field Results: JPL Mars Yard 2006 (1)

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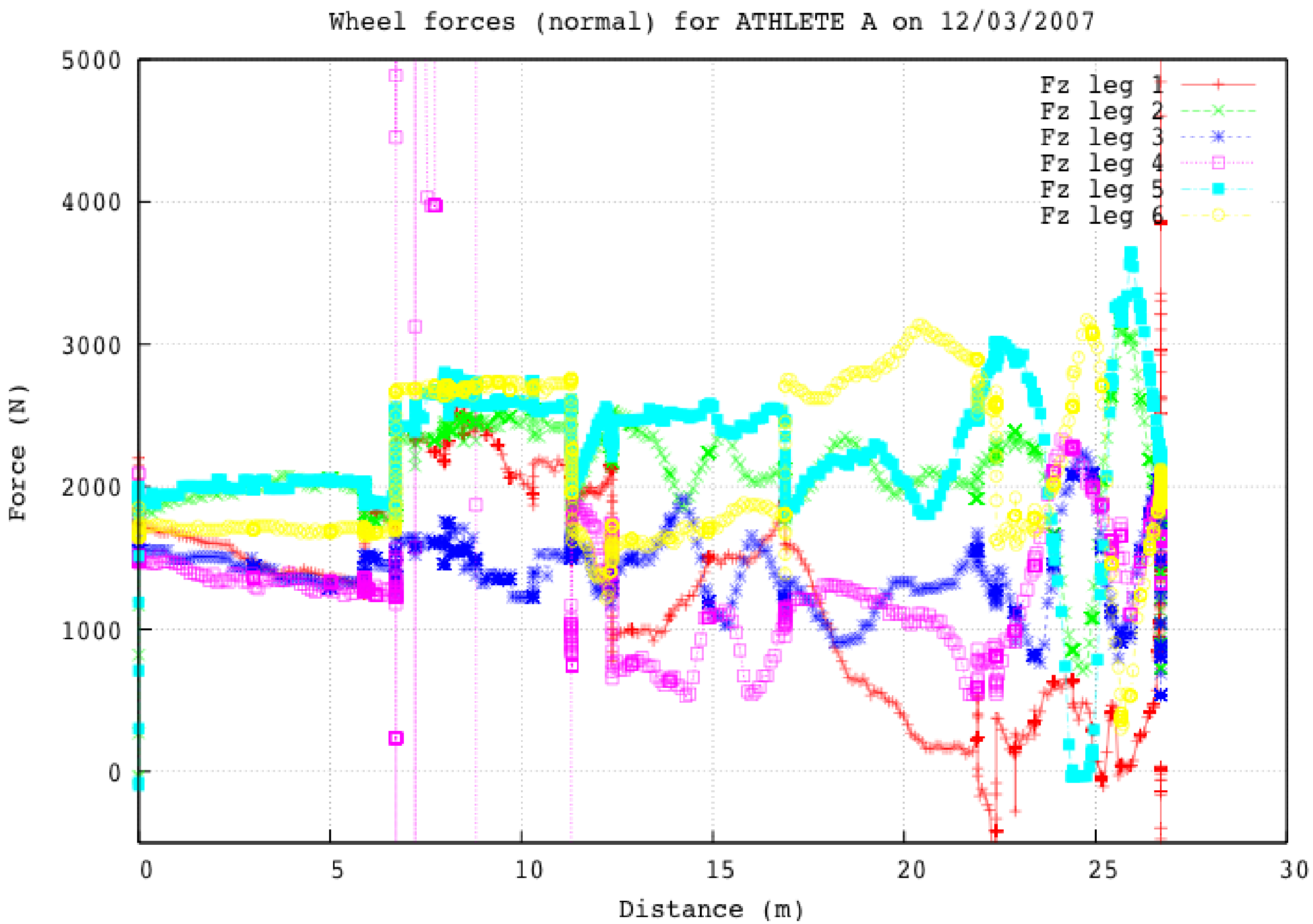
No Active Compliance



- Limbs start evenly loaded at ~1800 N
- Forces diverge by ~2000 N after driving 25m on benign terrain

Field Results: JPL Mars Yard 2006 (2)

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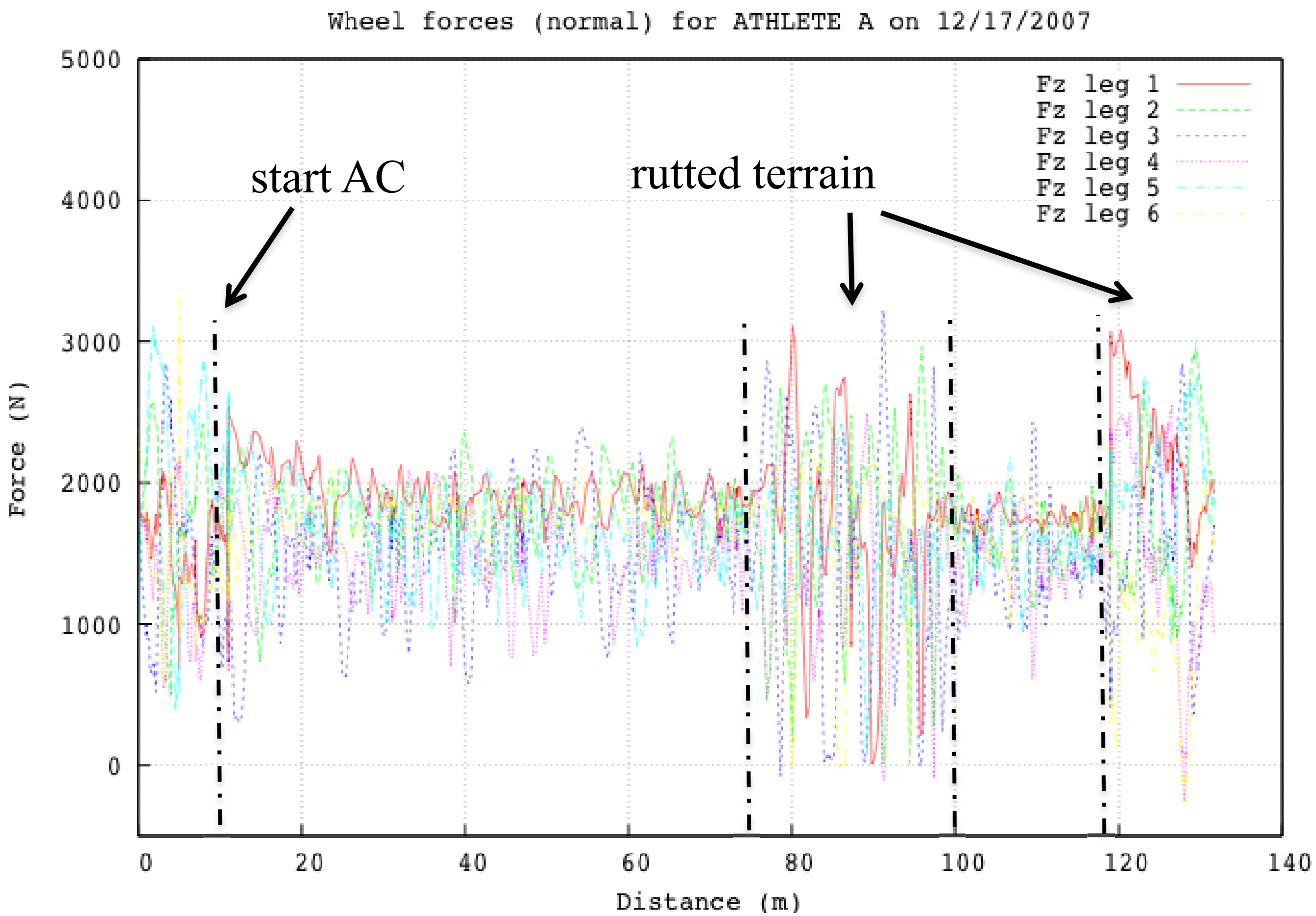
SDM-A with Active Compliance



- Limb forces converge when AC engaged
- Over bumpy, rutted terrain, forces vary but do not diverge

Field Results: Moses Lake 2007

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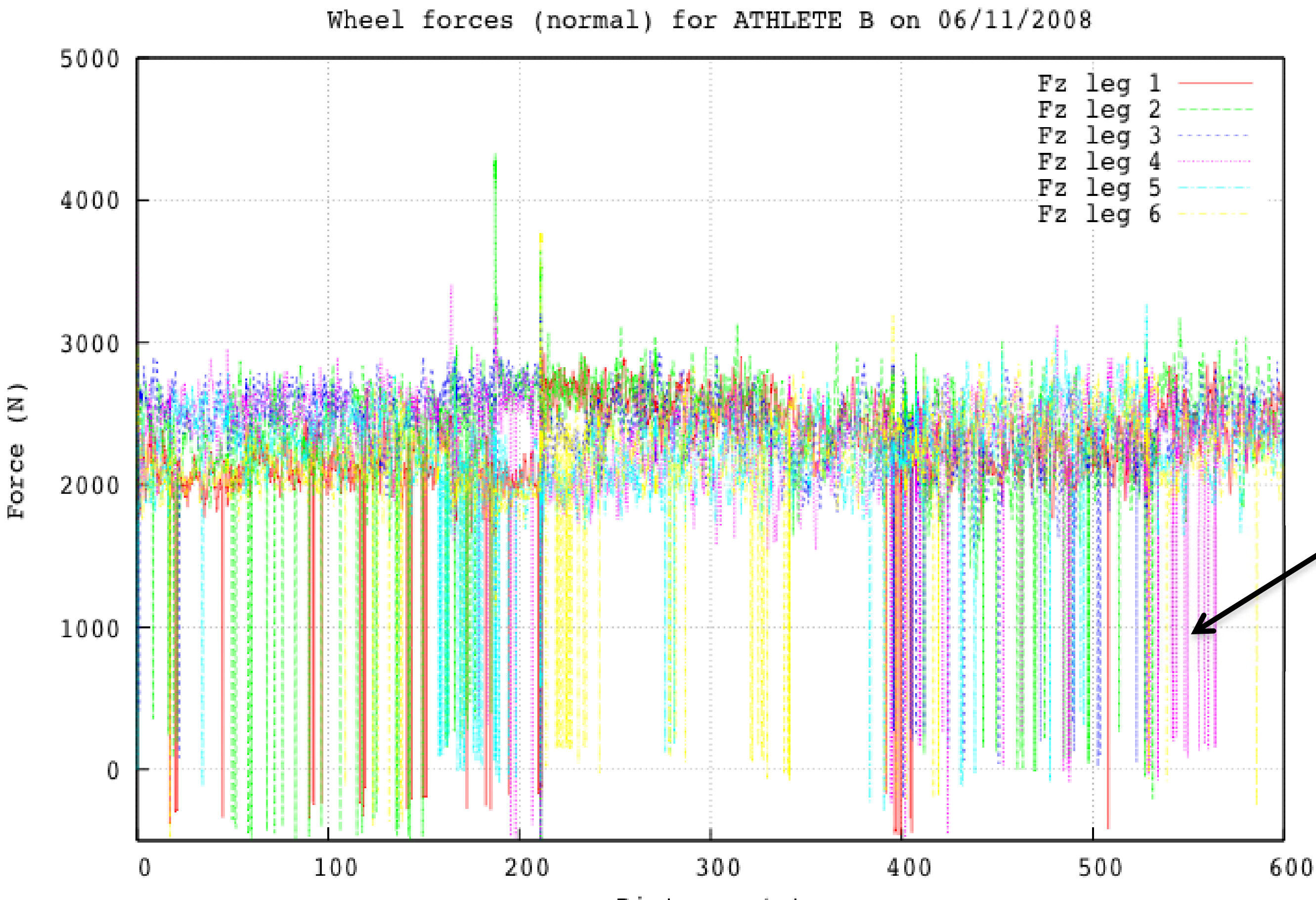
Long traverses using Active Compliance



Low-force spikes indicate limb lifted to refresh force estimate or reposition

- 8.8 km traversed by SDM-A & SDM-B with cargo over rolling sand dunes
- Limb forces reliably maintained near nominal 2300 N

Field Results: Black Point Lava Flow 2009 (1)

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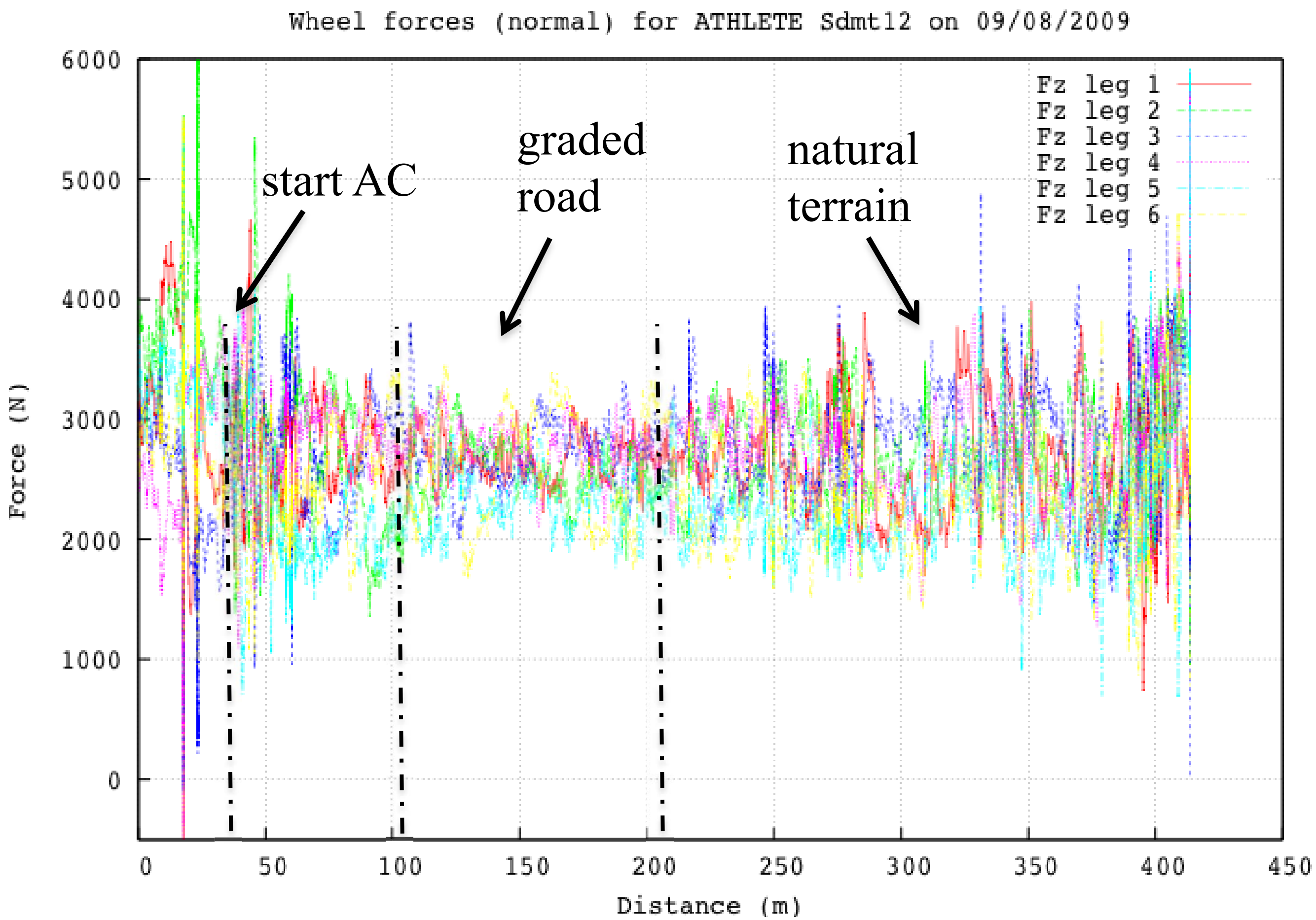
Driving SDM-T12 with Active Compliance



- Limb forces converge to nominal ~2800 N when AC is used
- Force variation increases with increased terrain relief, but doesn’t diverge

Field Results: Black Point Lava Flow 2009 (2)

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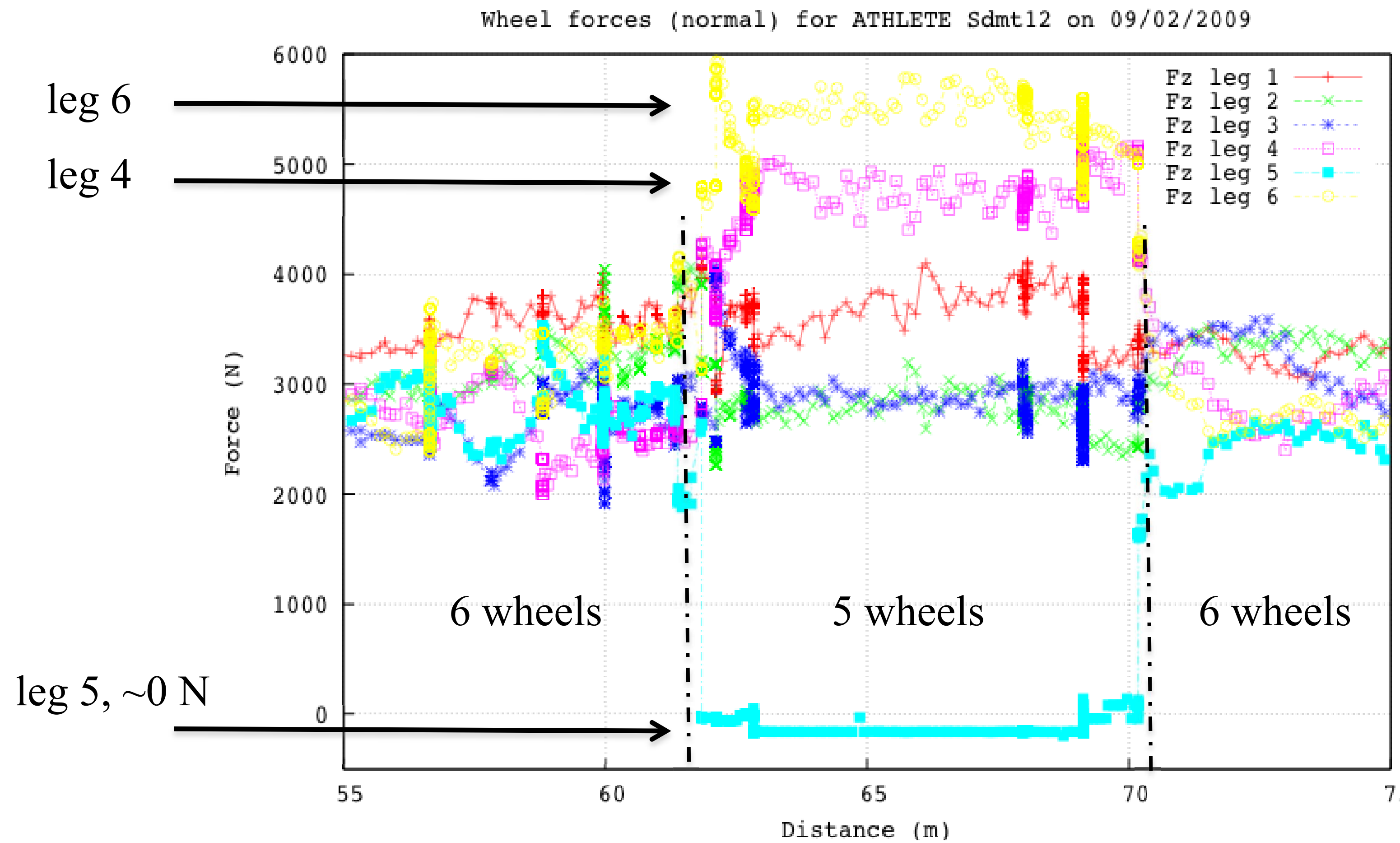
Active Compliance 5-leg force distribution



- Forces distributed evenly during 6-wheel driving
- With leg 5 lifted, algorithm maintains uneven distribution – greater nominal loading for legs 4 and 6.

Conclusions

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- Active Terrain Compliance
  - Effectively controls limb loading and vehicle pose on all existing ATHLETE prototypes
  - Has enabled traverses of >1 km per day over rolling natural terrain
  - Is effective for both symmetrical and asymmetrical loading conditions
- Future Work includes adapting the algorithm for a wider range of driving conditions
  - Longer traverse distances
  - Higher ground speeds
  - Improved slope-climbing capability

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