EC.721 Wheelchair Design in Developing Countries
Spring 2009

FITTING A WHEELCHAIR, BIOMECHANICS, AND DESIGN

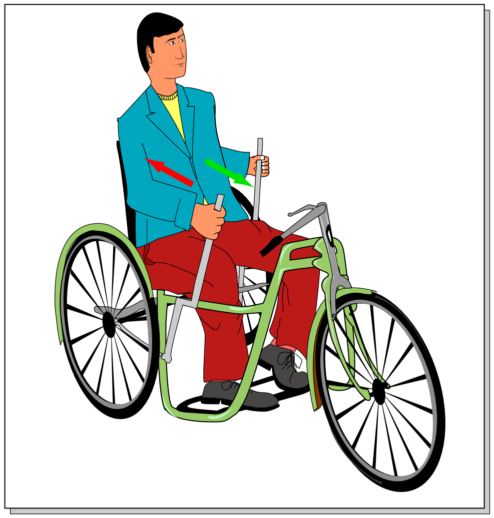

Figure by MIT OpenCourseWare.

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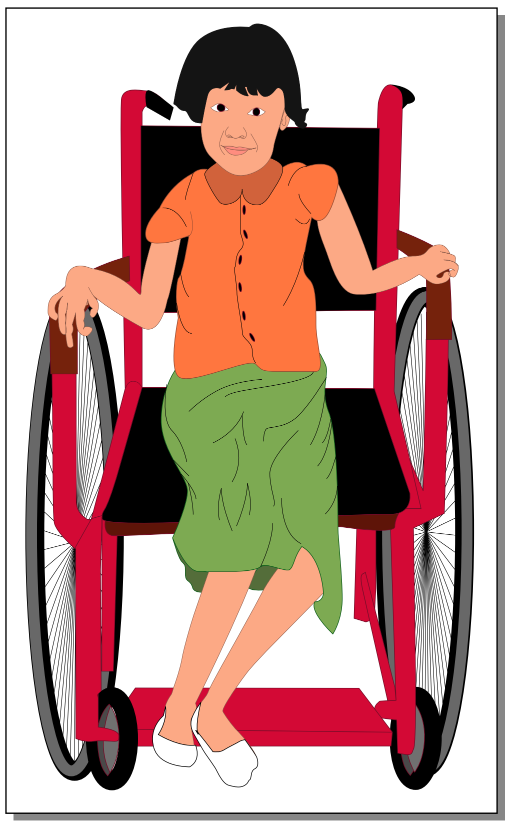
Source: http://doitfoundation.org/brasilito082305.htm



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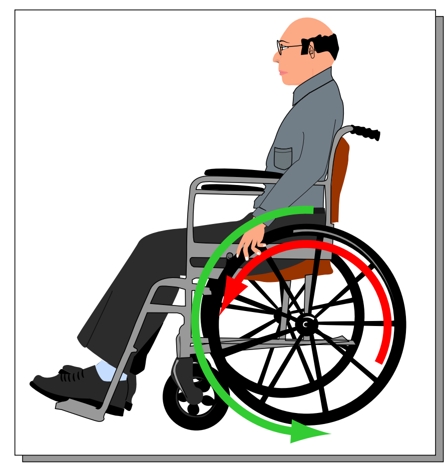

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CORRECT FITTING OF A WHEELCHAIR
Complications from improper fitting

Sitting habits

- Able bodied person – long period of sitting usually 1-2 hours, shifting weight all the time
- Disabled person may sit for 3 to 10 hours per day without repositioning

Complications due to poor posture

- Contractions and deformities
- Tissue breakdown
- Reduced performance and tolerance
- Urinary and respiratory infection
- Fatigue and discomfort

Free Wheelchair Mission Chair
(www.doitfoundation.org)

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CORRECT FITTING OF A WHEELCHAIR
Correct anatomical and wheelchair positions

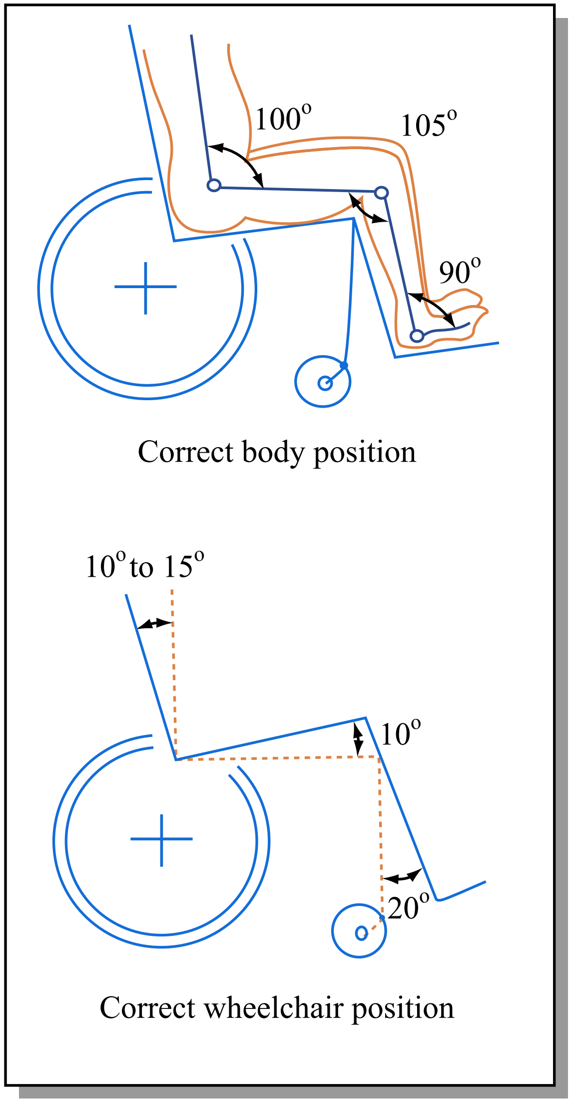


Figure by MIT OpenCourseWare. After Mayall, 1995.

- Want to distribute weight over butt and thighs
- Only want 1.25cm clearance between butt and frame

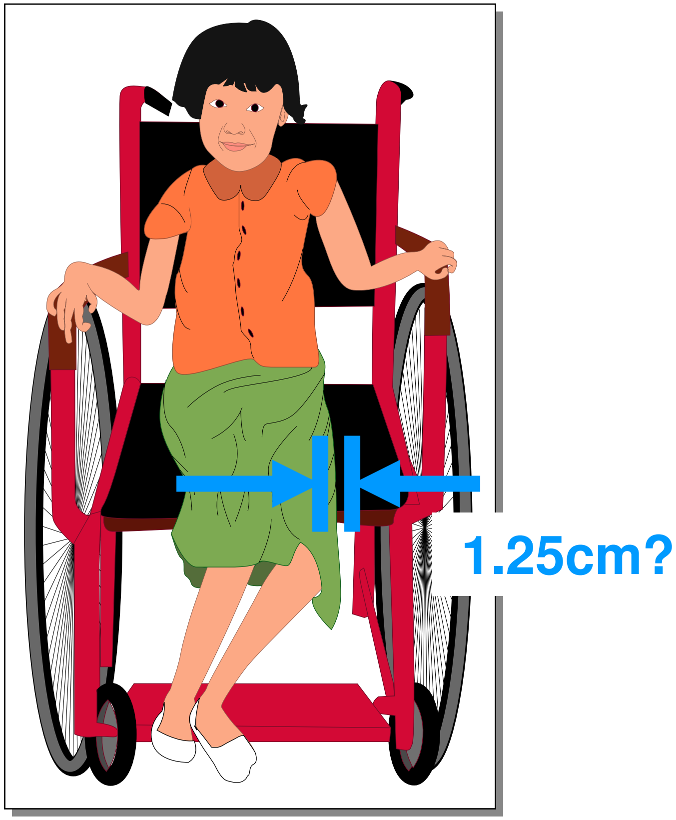


Figure by MIT OpenCourseWare.

CORRECT FITTING OF A WHEELCHAIR
Considerations during assessment

Considerations during prescription

- Diagnosis and prognosis
- Age
- Communication status
- Cognitive function
- Perceptual function
- Physical ability
- **Level of independence in activities during daily living**
- Transfer ability and modality
- Mobility (ambulation and wheelchair mobility)
- Body weight
- Sensory status
- Presence of edema
- Leisure interests
- **Transportation to and from home**
- **Roughness of usage**
- Time spent in wheelchair daily
- **Financial resources of patient**

List from (Mayall, 1995)

Wheelchair Foundation in Tanzania

Tanzania Big Game Safari:

•Largest donator in Tanzania, giving away nearly 7,000 chairs so far.

•Said Wheelchair Foundation will give a chair to anyone who seems to need one – a loose requirement that may include people who are crawling on the ground to people who may walk with a crutch.

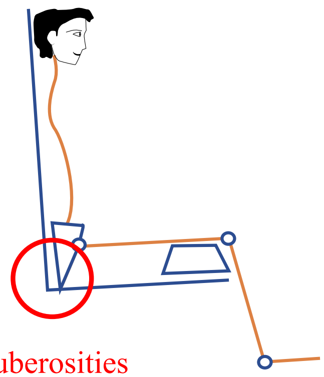
•Admitted they get so many chairs every year that after the first few hundred have been distributed, it is very difficult to find genuinely disabled people to whom they can give them.

Monduli Rehab Center:

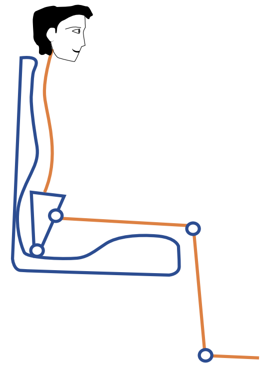
•Criticized the WC Foundation and said wheelchairs should not be given out like candy.

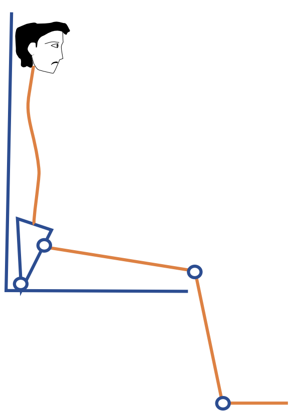
•Because the village terrain is so rough, people should be encouraged to walk with crutches or braces, and WCs should be a last resort.

CORRECT FITTING OF A WHEELCHAIR
Cushioning and positioning



Pelvis positioning with a pre-ischial bar.


Pelvis positioning with contoured firm seat and back.


Pelvis positioning without a pre-ischial bar.

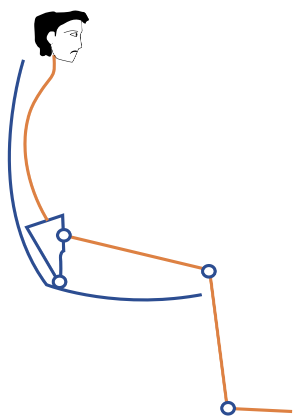

Pelvis positioning with a sling seat and back.

Figure by MIT OpenCourseWare. After Mayall, 1995.

Pressure Sores
(Close eyes if squeamish)

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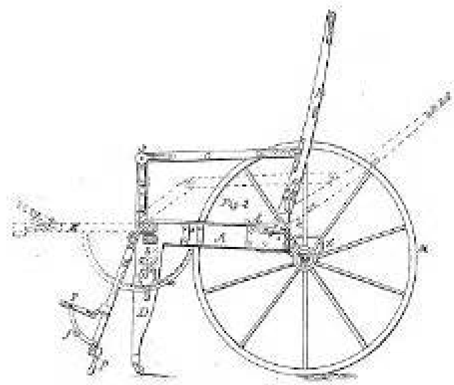
WHEELCHAIR PROPULSION



First US wheelchair patent
A.P. Blunt, et. all., 1869

Photos removed due to copyright restrictions.

- Wheelchair propulsion 2-10% efficient (Woude et al, 1986, 1998)
- Optimal human chemical-mechanical whole body efficiency ~ 25% (Mark's STD Handbook, 1978)
    - Occurs at ½ max muscle force and ¼ max muscle speed
    - Optimal efficiency and max power output do not occur together → **Engage more muscles for more power**

Determine best system → Wheelchair propulsion project

UROP: Mario Bollini

- Determine the upper body motion that yields highest sustainable power at highest efficiency to deterministically design a wheelchair drive system

Previous work: **Power output measured from different drive systems**

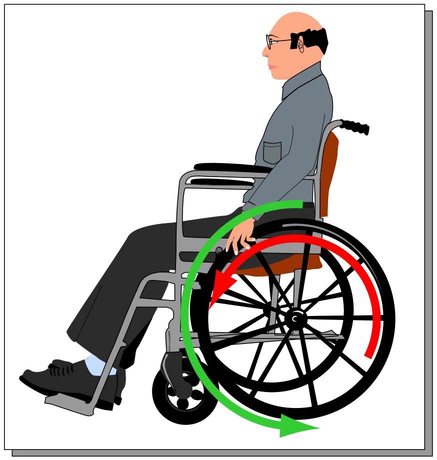
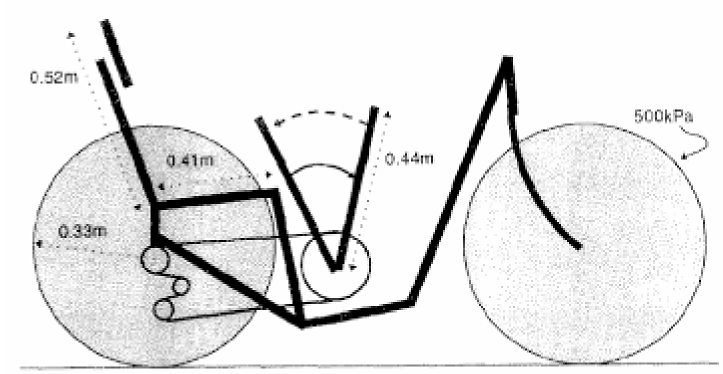


Figure by MIT OpenCourseWare.

Conventional chair

$P_{out} = 26.5W$

(van der Linden, et al, 1996)



Lever-powered tricycle

$P_{out} = 39.3W$

(van der Woude, et al, 1997)

Motivation: **To deterministically design a drive system for long and short distance travel, the maximum available efficient power should dictate the design**

$$\eta P_{human} = \eta T_{human}\,\omega_{human} = P_{out} = F_{resist} V_{device} = F_{resist} R_{wheel}\,\omega_{wheel}$$

TBD

dictated by environment

calculated

$$\frac{\omega_{wheel}}{\omega_{human}} = Gear\ Ratio$$

tune through design

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WHEELCHAIR PROPULSION RESEARCH

Upper body biomechanics data

Fifth-percentile arm strength (N) exerted by sitting men													
(1)	(2)		(3)		(4)		(5)		(6)		(7)		
Elbow flexion (deg)	Pull		Push		Up		Down		In		Out		
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	
180	222	231	187	222	40	62	58	76	58	89	36	62	
150	187	249	133	187	67	80	80	89	67	89	36	67	
120	151	187	116	160	76	107	93	116	89	98	45	67	
90	142	165	98	160	76	89	93	116	71	80	45	71	
60	116	107	96	151	67	89	80	89	76	89	53	71	

Figure by MIT OpenCourseWare.

(Shigley, Mischke, 1996)

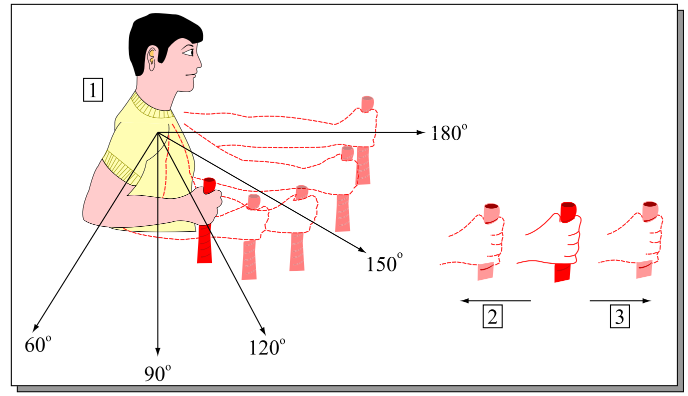
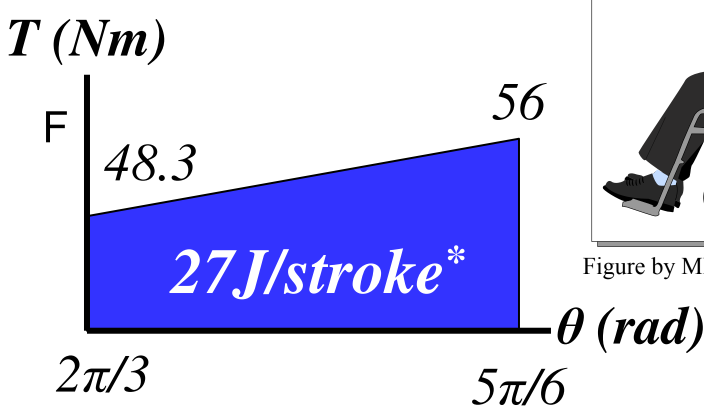
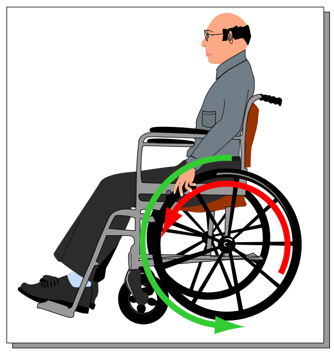


Figure by MIT OpenCourseWare.

Single arm energy output





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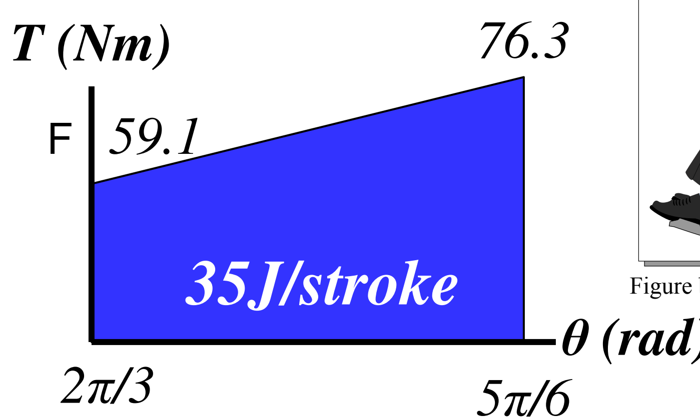

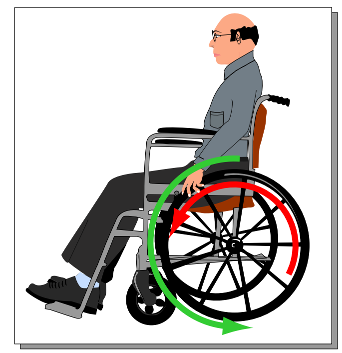

Figure by MIT OpenCourseWare.

Conventional wheelchair propulsion

Opposed handrim-wheel rotation

*2% error from van der Linden, et al, 1996

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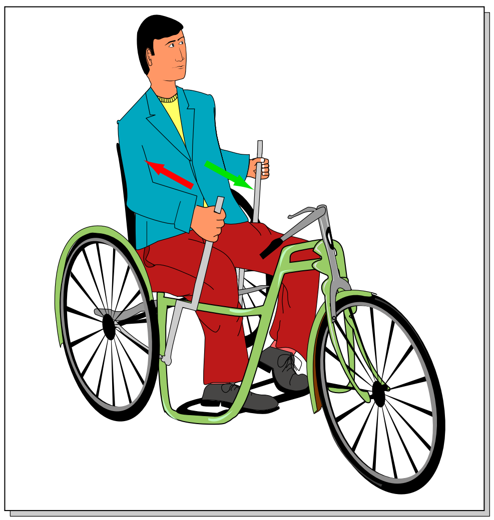
WHEELCHAIR PROPULSION RESEARCH



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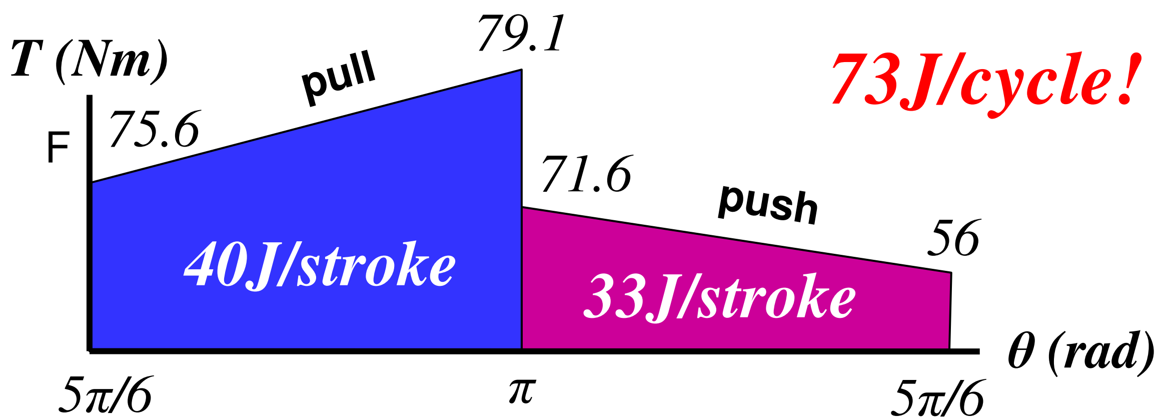
Single arm energy output



Rowing-motion propulsion

Additional questions

- **What unidentified upper body motions can give high power output**
- **How different disabilities affect range of motion**
- **What type of resistance forces will be encountered depending on the environment**

Variable speeds through a fixed geartrain

Geartrain performance

Difference between chair velocity (V_{Chair}) and hand velocity (V_{Hand})

$$\boxed{\frac{V_{Chair}}{V_{Hand}} = \frac{D_{CR} R_W}{D_{FW} L}}$$

LFC DEVELOPMENT
Lever sizing

Pushing power at peak efficiency, young male: 19.6W @ 51N and 0.38m/s
Max pushing force at slow speed (both hands), 50% male: 356N

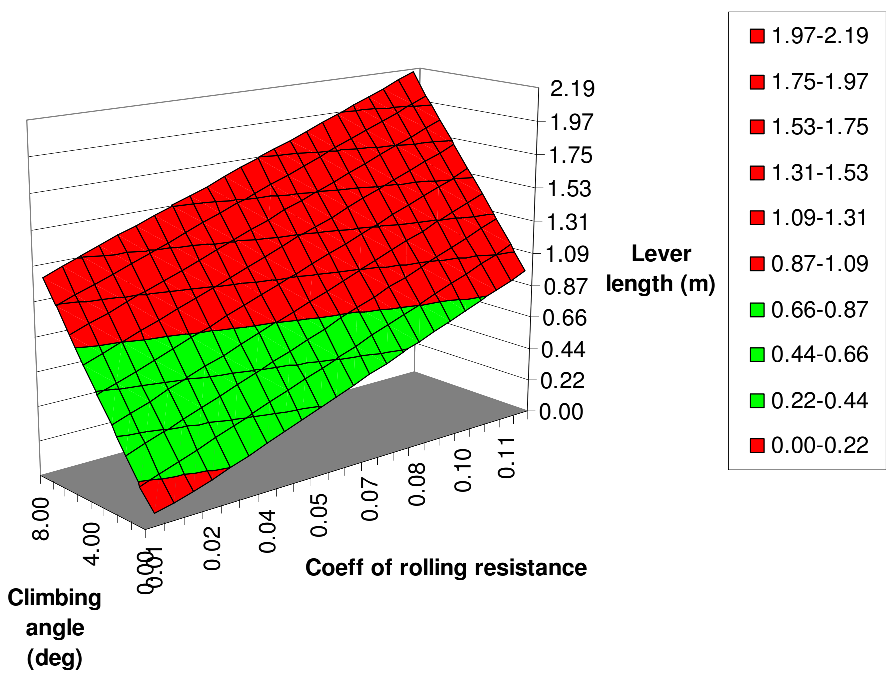
Power balance at peak efficiency:

$$\eta P_{In} = P_{Out} \Rightarrow \eta P_{Human} = \eta F_{Hand} V_{Hand} = P_{Drag} + P_{Rolling} + P_{Gravity}$$

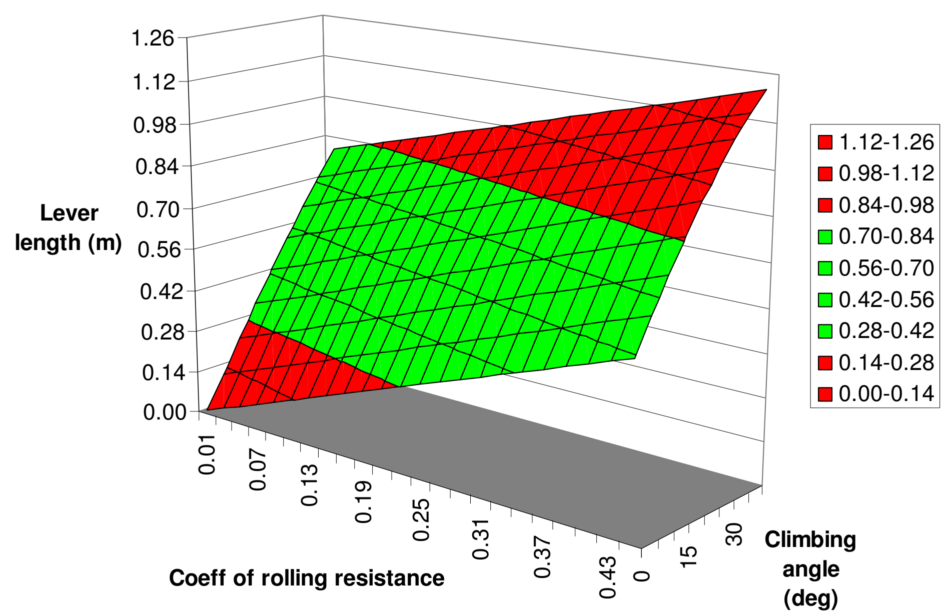
$$\eta F_{Hand} V_{Hand} = C_D \frac{1}{2} \rho_{air} A \left(V_{Chair}\right)^3 + mg\left(V_{Chair}\right)\left[\mu \cos\theta + \sin\theta\right]$$

Force balance at peak force: $F_{Resist} = F_{Rolling} + F_{Gravity} = mg\left[\mu \cos\theta + \sin\theta\right]$

Lever length (m) for 36T chainring and 20T freewheel



Lever length (m) for 36T chainring and 20T freewheel



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LFC DEVELOPMENT
Off-road testing

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POWERED TRICYCLE CALCULATIONS

Courtesy of Kien Tuong Private Enterprise. Used with permission.

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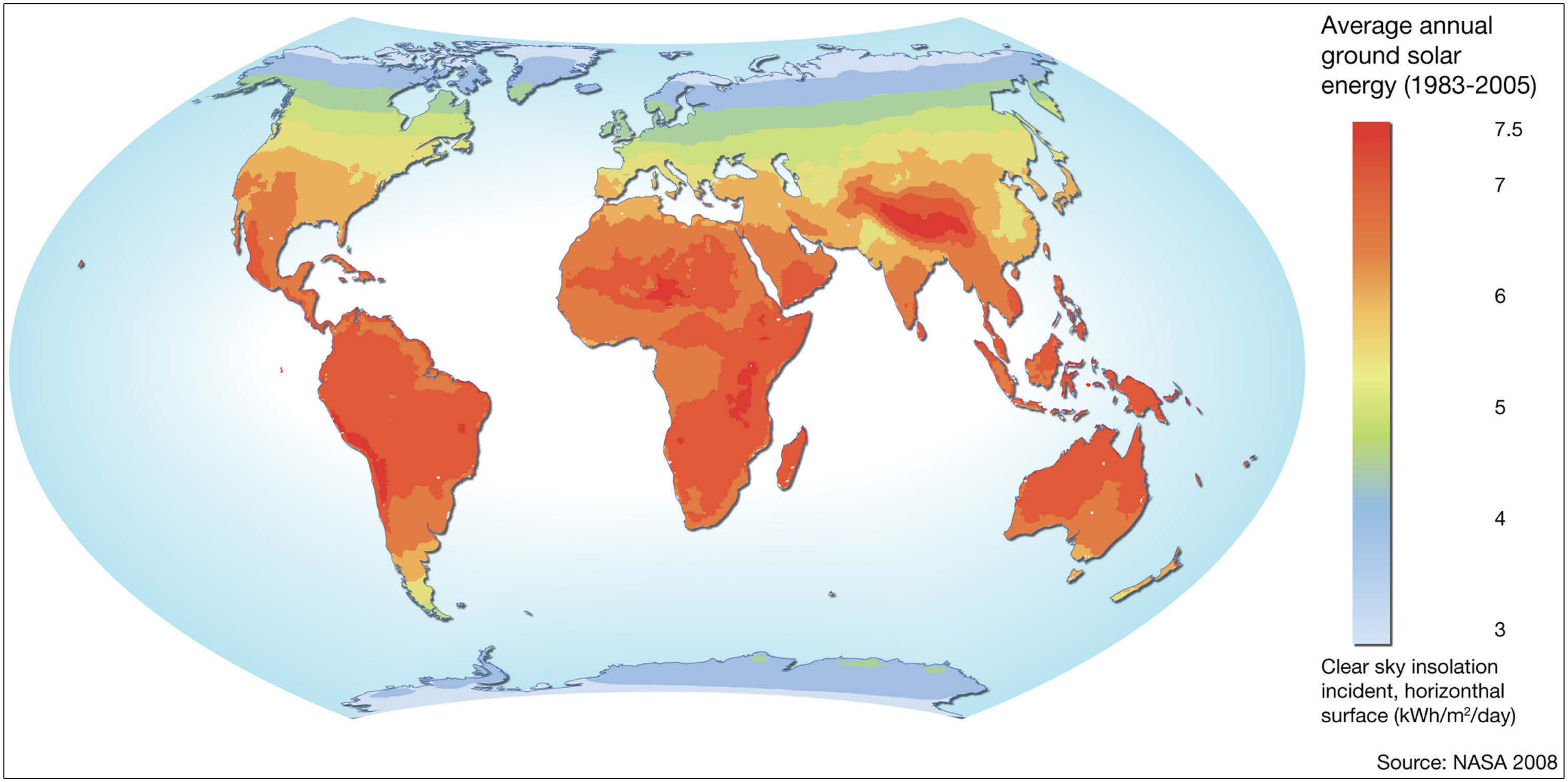
SOLAR ENERGY DISTRIBUTION



Map by Hugo Ahlenius, UNEP/GRID-Arendal. Courtesy of UNEP / Grid-Arendal.
http://maps.grida.no/go/graphic/natural-resource-solar-power-potential

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DESIGN FOR HUMAN USE
Safety factors

Uncertainties in strength

$\sigma_p = \sigma_y / n_s$

Where σ_p = permissible stress,
σ_y = yield strength,
n_s = strength factor of safety
(typically 1.2 to 1.4)

Uncertainties in Loading

$F_p = F_y / n_L$

Where F_p = permissible load,
F_y = max load,
n_L = strength factor of safety

$$\boxed{n_{total} = n_s n_L}$$

For machines that can cause injury or death, n_{total} is typically 4 to 10+

When choosing a safety factor, consider:

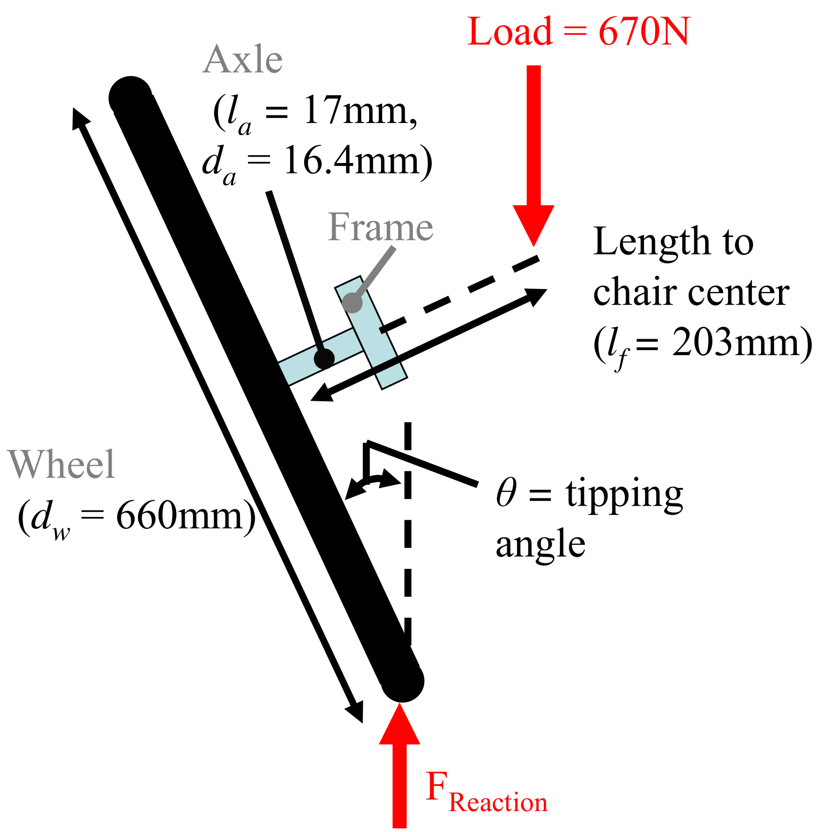
- Does the load come from human activity
- Does loading come from natural sources (terrain, etc)
- What are the consequences of failure?
- Is the loading due to a prelaod?
- Does the load come from a power source (ex. starting vs. steady torque)?
- Does the load come from driven machinery that can change its output?

Theory adapted from: Shigley, 1983, Wikipedia, 2007

EXAMPLE
Estimating loading factor in bicycles (drop case)

http://www.youtube.com/watch?v=tMmiN6M7GXs&feature=PlayList&p=AE40D5B0BDD7EE81&playnext=1&index=9

EXAMPLE
Estimating stress in wheelchair axle during tip-over



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EXAMPLE
Stress in cantilevered Cannondale front shock

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HOMEWORK

- Reading from Positioning in a Wheelchair
- Have first group meeting, define Functional Requirements and project scope, and send to Mentors and Community Partners for Review
- Pick first presentation day (March 3rd, 7-8:30pm???) will present strategies then

CLASS ACTIVITY
Measuring human power output

Next class: Meet in lab

Break into teams of 4 to 5, get a mobility aid from office, and go to tunnels in basement

Tasks:

- **Measure the rolling resistance of your team's mobility aid and calculate the coefficient of rolling friction**
- **Measure your MAX mechanical power output on a flat surface for each person in the group (must travel at least 50 feet). Can use rolling start to negate transient effects.**
- **Estimate the angle of one of the tunnel ramps (you can do this mathematically and/or experimentally – don't just eyeball it)**
- **Measure each group member's mechanical power out while going up a ramp. (Note: one wheelchair team should go up backwards)**