Foot Marches and The Infantry Weight Load

A Physiological-Mathematical Model

Background

- One of the most significant trend that emerges across land forces modernization efforts in the last decade is the growing importance of development programs that are devoted to the infantry
- All these programs aim to enhance and expand the capabilities of the individual soldier
- Each of these programs emphasize the necessity of **reducing the individual soldier's weight load**

Operational Weight Load Constraints [FM 21-18]

- “To prevent an individual load from hindering a marching soldier’s mobility and combat readiness, **commanders must reduce the carried load to the minimum mission-essential and survival equipment**.”
- "The fighting load should not exceed 48 pounds (~21kg), and the approach march load (that includes the fighting load) should be less than **72 pounds (~32 kg)**….”

How Realistic are these Operational Weight Load Constraints?

Basic Gear	
Combat Boots	1.6 kg
Field Uniform	1.8 kg
M-16	3.2 kg
5 Cartridges	2.3 kg
2 Water Canteens	3.0 kg
Light Pack	1.8 kg
Helmet	1.5 kg
Total	~15 kg

Weapon Characteristics	
AT Missile	12 kg
MK19 – 40 mm Grenade Machine-Gun	35 kg
M2 Browning Machine-Gun 0.5'	28 kg
81mm Mortar	18 kg

[FM 3-21-12,2008]

How Realistic are these Operational Weight Load Constraints?

- They are neither enforced nor obeyed, so what is the signicifance of carrying more?
- **We lack tools that enable us to analyze the dependencies between weight load and combat capabilities**
- As a result we developed the **F**oot **M**arch **W**eight **L**oad (FMWL) model that is described next
- This model enables us to describe and analyze the dependencies between the soldier's weight load and his sustainable ability to carry it

FMWL Model – Physiological Background

- There are three physiological mechanisms that limits our ability to endure sustainable physical strain:
  - **Cardio-lung system** – our ability to convert chemical energy to muscle energy
  - **Skeletal-muscle systems** – physical strength
  - **Heat balance mechanism** – our ability to maintain proper body temperature
- Assuming maximum comfort and good physical shape, the main mechanism that limits our ability to operate is the **body heat balance**

Physiological Background (continued)

- In order to perform any physical work, the human body uses metabolic processes to convert chemical energy into muscle mechanical energy
- On average, the efficiency of these processes is about 10%
    - The human body produces 10 times more energy than necessary for a given physical action
    - 90% of this energy is stored in our body in a form of heat
- Sustaining a physical effort depends on our ability to release the excess heat and to maintain proper **Heat Balance**
- Improper heat balance may lead to an increase or a decrease of the body temperature
- A change of 2-3°C in body temperature from 37°C can severely limit physical and cognitive performance

Physiological Background (continued)

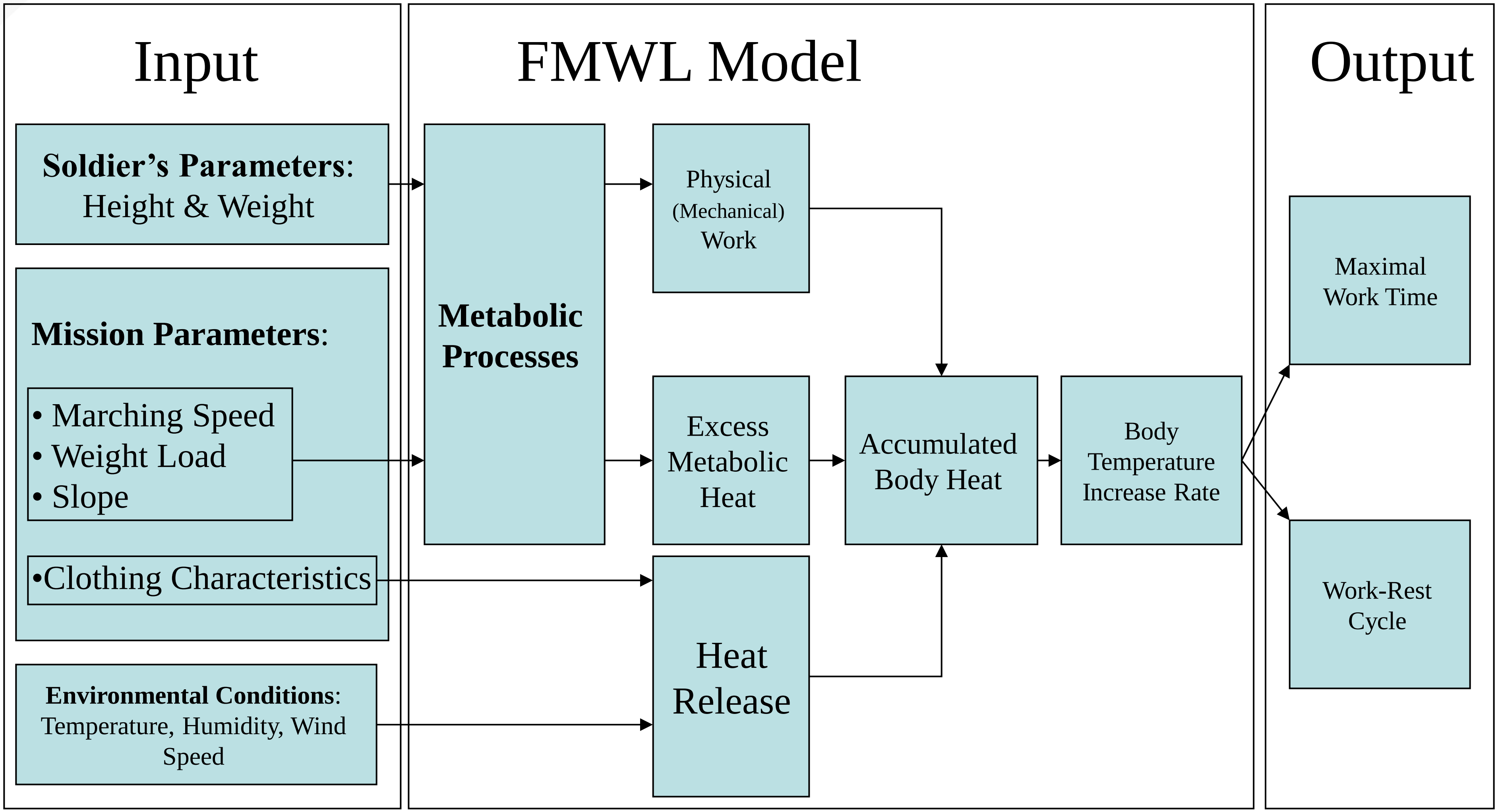
- Human heat balance and the factors that affect it are well studied both theoretically and empirically. This knowledge can be employed for our purposes, and incorporated in our model

FMWL Model - Input

- **Soldier's parameters**: height and weight
- **Mission parameters**:
  - Marching speed
  - Weight load
  - Slope
  - Clothing characteristics – thermal resistance and evaporative diffusion coefficients
- **Environmental conditions**:
  - Temperature
  - Humidity
  - Wind speed
  - Radiation temperature

FMWL Model - Output

- Maximal work time, where work is defined by marching with a given weight on a given slope
- Recommended work-rest cycles for long lasting efforts
- Average sustainable speed for a given long-duration mission


Input
FMWL Model
Output
Soldier's Parameters:
Height & Weight
Mission Parameters:
• Marching Speed
• Weight Load
• Slope
•Clothing Characteristics
Environmental Conditions:
Temperature, Humidity, Wind Speed
Metabolic Processes
Physical (Mechanical) Work
Excess Metabolic Heat
Heat Release
Accumulated Body Heat
Body Temperature Increase Rate
Maximal Work Time
Work-Rest Cycle

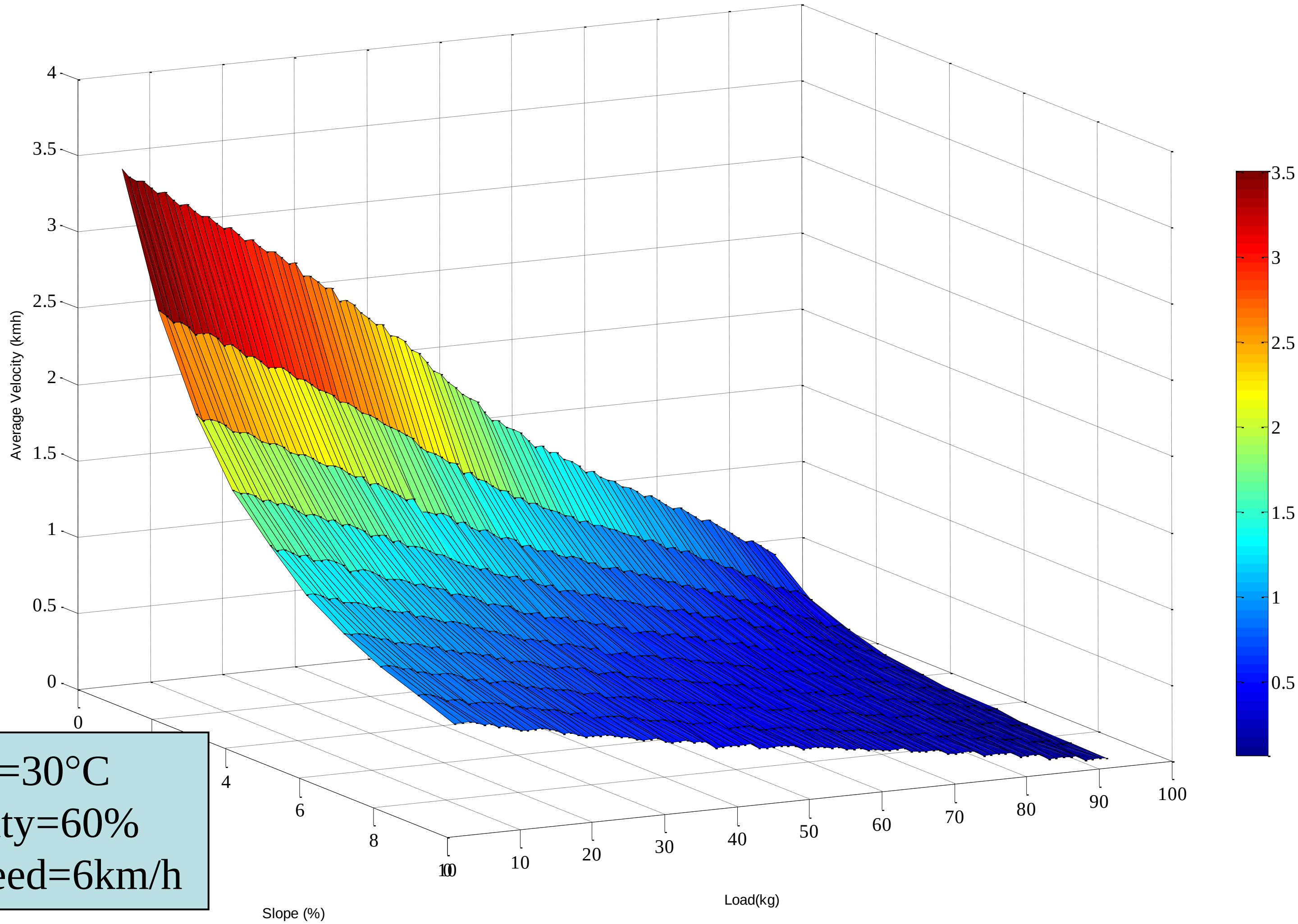
Metabolic Rate – Pandolf and Givoni Models

$$M = 1.5 \cdot W + 2 \cdot (W + L) \cdot (L / W)^2 + \eta \cdot (W + L) \cdot \left(1.5 \cdot V^2 + 0.35 \cdot G \cdot V\right)$$

- M – metabolic rate (Watt)
- W – body weight (kg)
- L – weight Load (kg)
- η – terrain factor
- V – walking speed (km/h)
- G – slope (%)

Some Results

Average speed as a function of Weight Load (kg) and of the Slope (%)



Temp=30°C
Humidity=60%
Wind Speed=6km/h

Some Results

Average speed as a function of Weight Load (kg) and of the Slope (%)

- One can use the data that was generated by numerical analysis and employ data fitting methods, thus quantifying in a simplified form the dependence of the average sustaibable speed on the weight load and the slope
- It appears that the most fitting surface is a plane of the following form

$$V = 3.36 - 0.06 \cdot G - 0.03 \cdot L$$

Average Speed (km/h)

Slope (%)

Weight Load (kg)

Summary

- As expected, the average speed decreases as the weight load or the slope increase
- It appears that a linear dependency is a good estimate
- The marginal decrease in the average speed for an increase of 1 kg in the weight load is about 0.03 km/h
- The marginal decrease in the average speed for an increase of the weight load and an increase of the slope has the same magnitude