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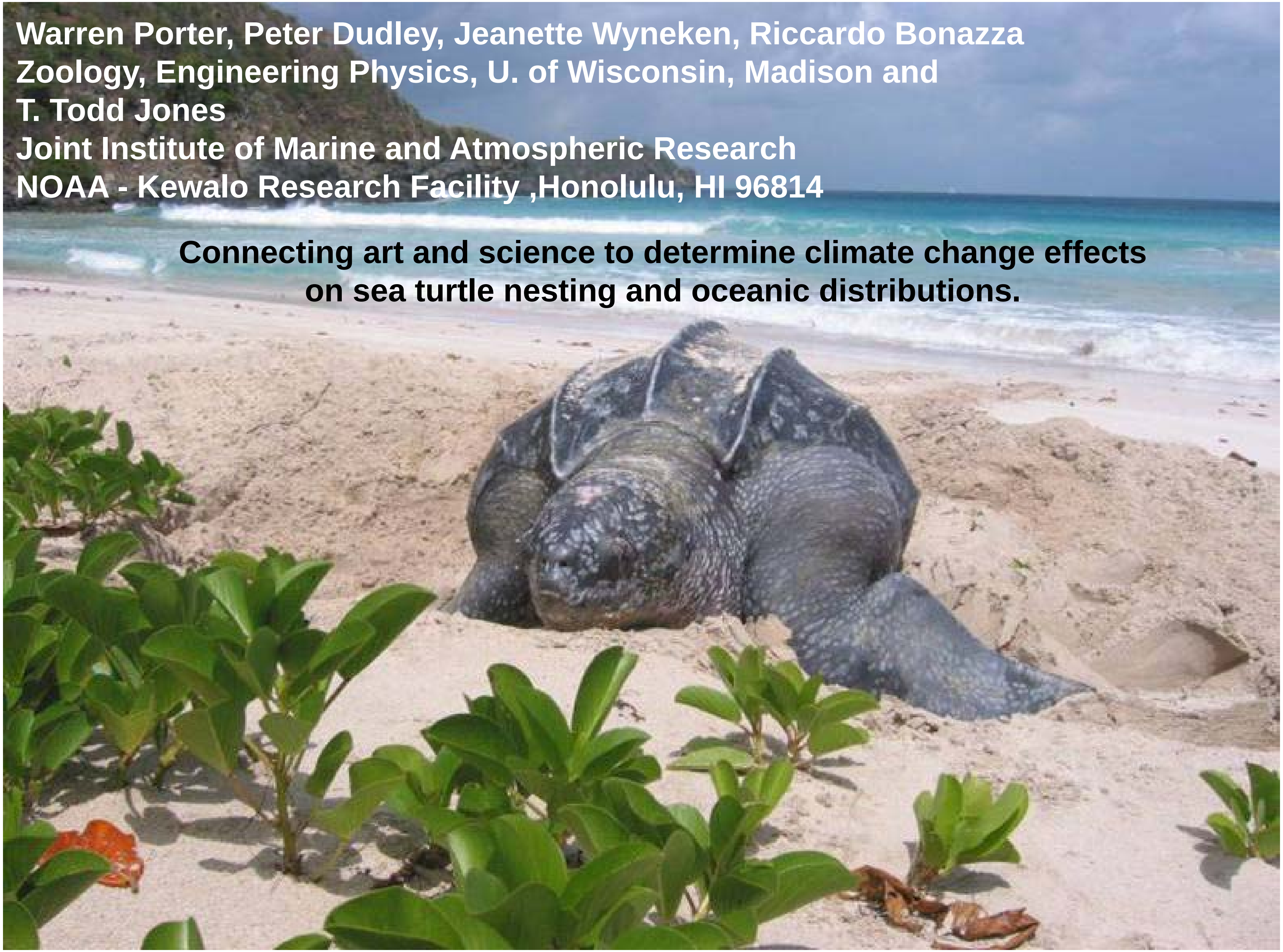
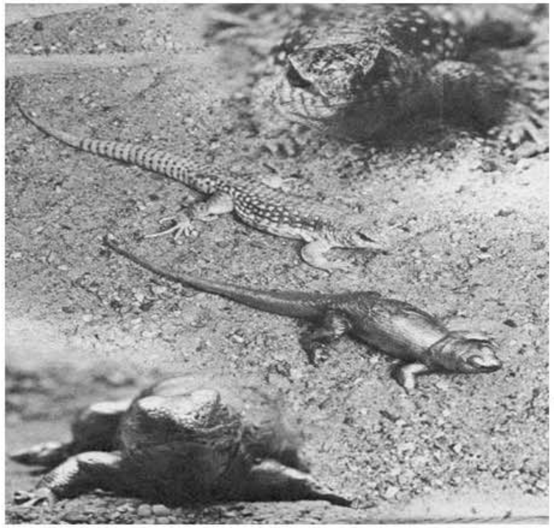
NOAA - Kewalo Research Facility ,Honolulu, HI 96814

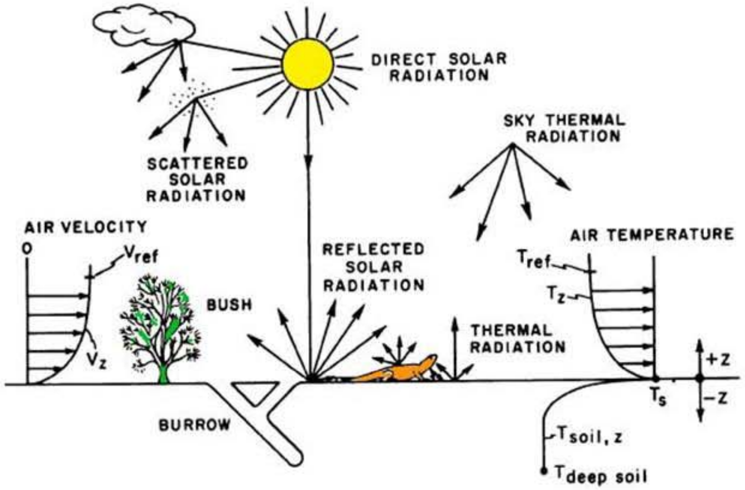
Connecting art and science to determine climate change effects on sea turtle nesting and oceanic distributions.



A brief history… microclimate and animal heat and mass transfer

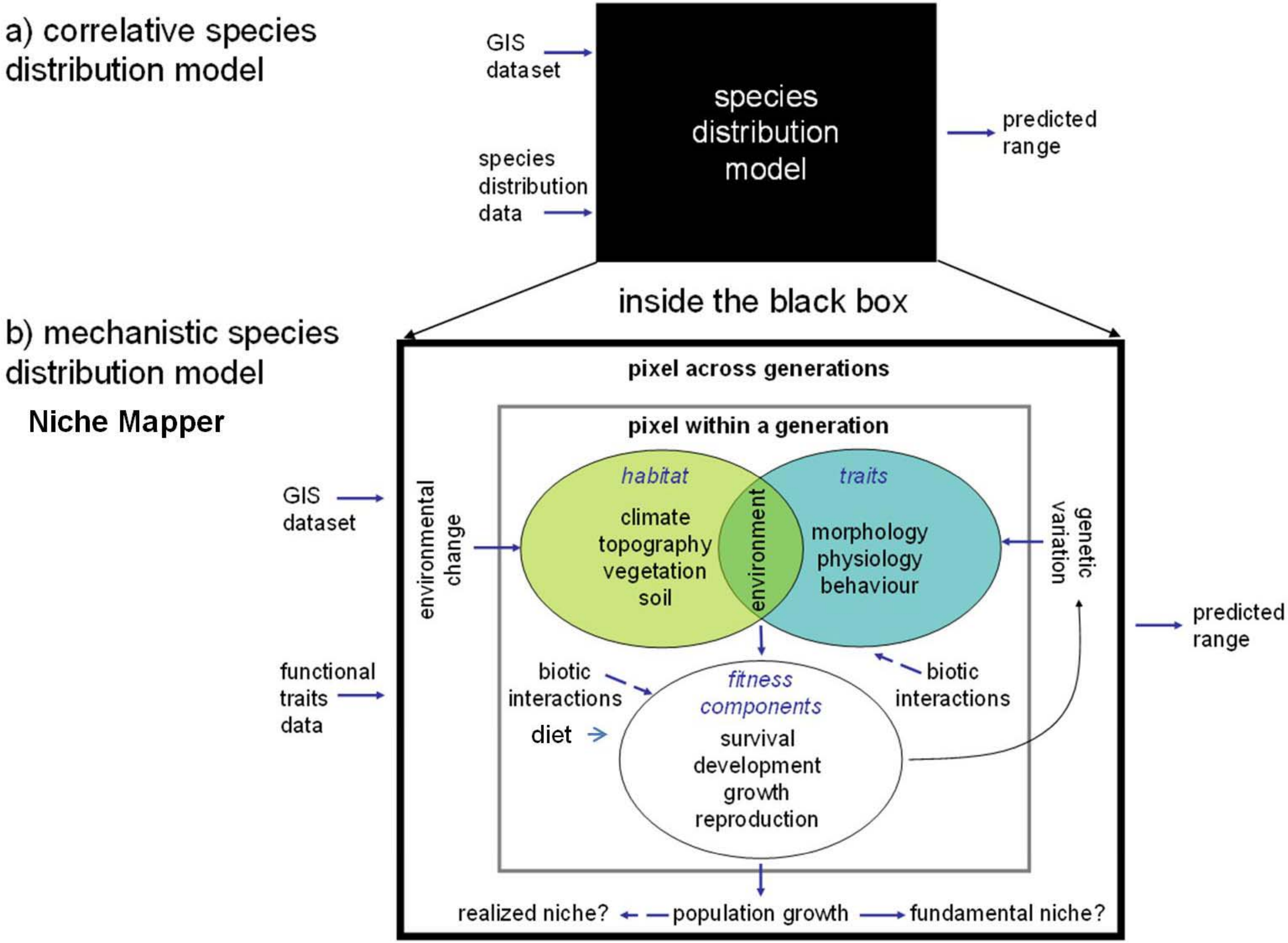
www.zoology.wisc.edu/faculty/Por/Por.html





Outline

1) Overview
2) Connecting momentum, heat and mass balances to energetics, behavior and distributions now and in the future.
3) Model development and tests for terrestrial and marine environments and animals (Niche Mapper) and computational fluid dynamics (CFD) for swimming virtual leatherbacks.


a) correlative species distribution model
GIS dataset
species distribution data
species distribution model
predicted range
inside the black box
b) mechanistic species distribution model
Niche Mapper
GIS dataset
functional traits data
pixel across generations
pixel within a generation
environmental change
habitat
climate
topography
vegetation
soil
environment
traits
morphology
physiology
behaviour
genetic variation
predicted range
biotic interactions
biotic interactions
diet
fitness components
survival
development
growth
reproduction
realized niche?
population growth
fundamental niche?

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How can we make the connections between

Global climate change

Local environments

Animal design

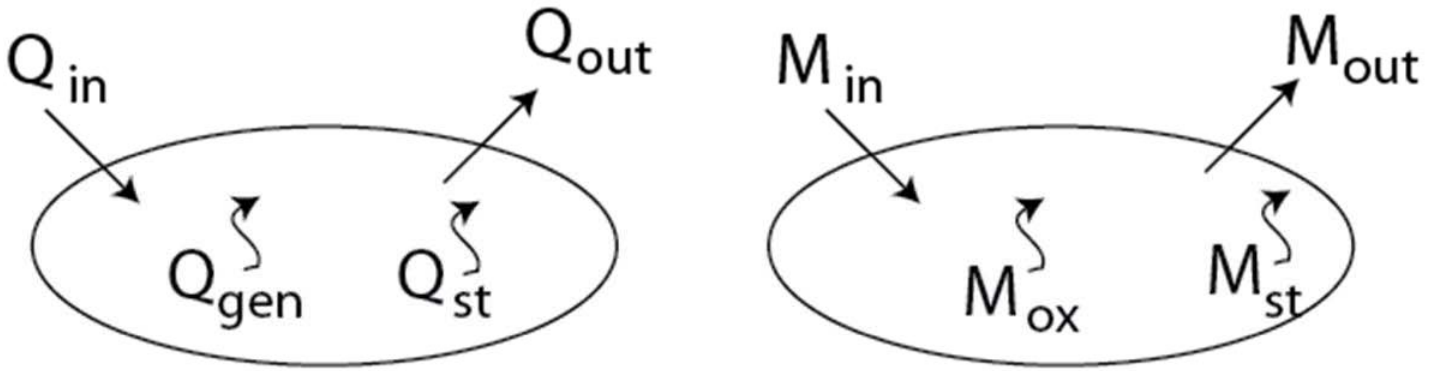
Physiological and behavioral properties?

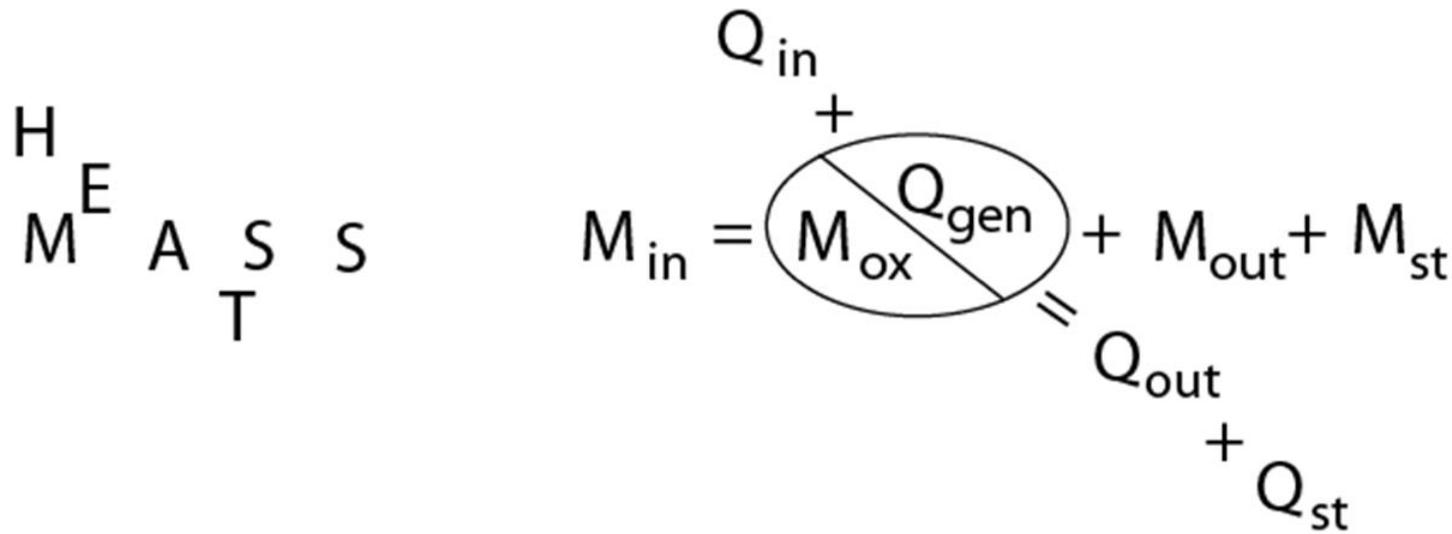
We start by drawing pictures…

Terrestrial

Climate change and Physiology

HEAT — MASS



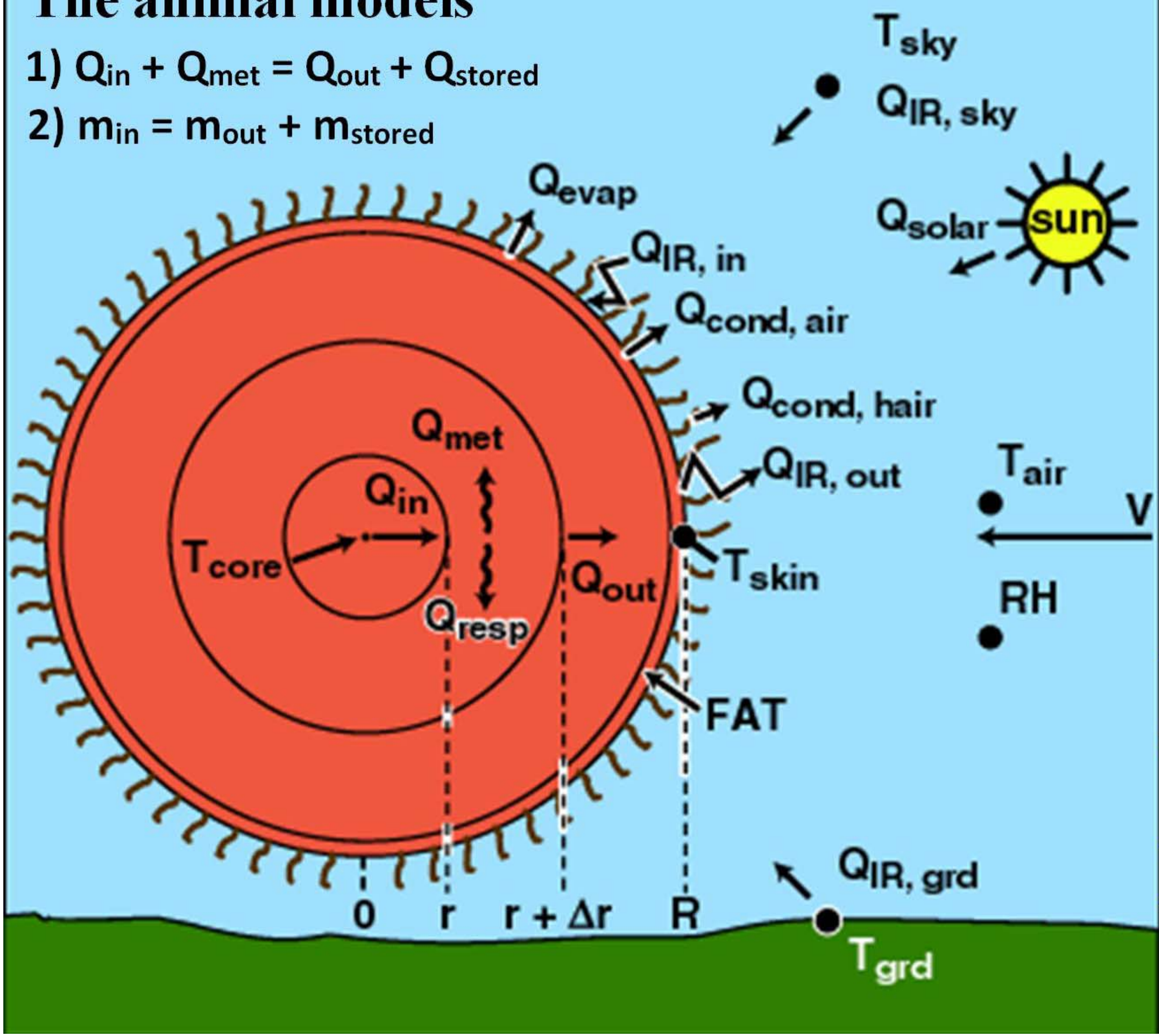


Draw it, write the equations from the arrows in the picture

The animal models

1) $Q_{in} + Q_{met} = Q_{out} + Q_{stored}$

2) $m_{in} = m_{out} + m_{stored}$

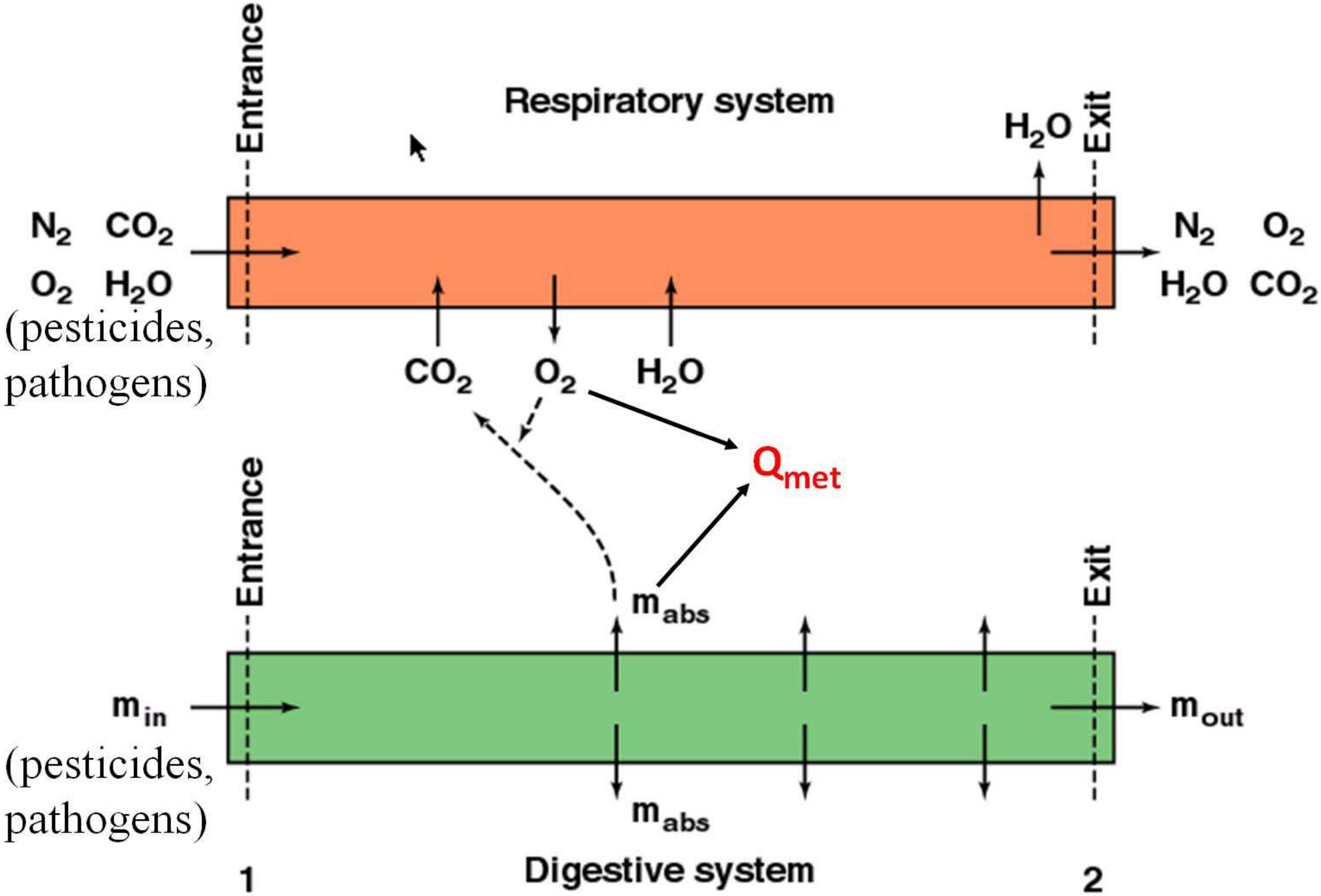


T_{core} ->

Q_{met} = ?

T_{core} – T_{skin} -> behavior

Internal mass balance models coupled to heat transfer



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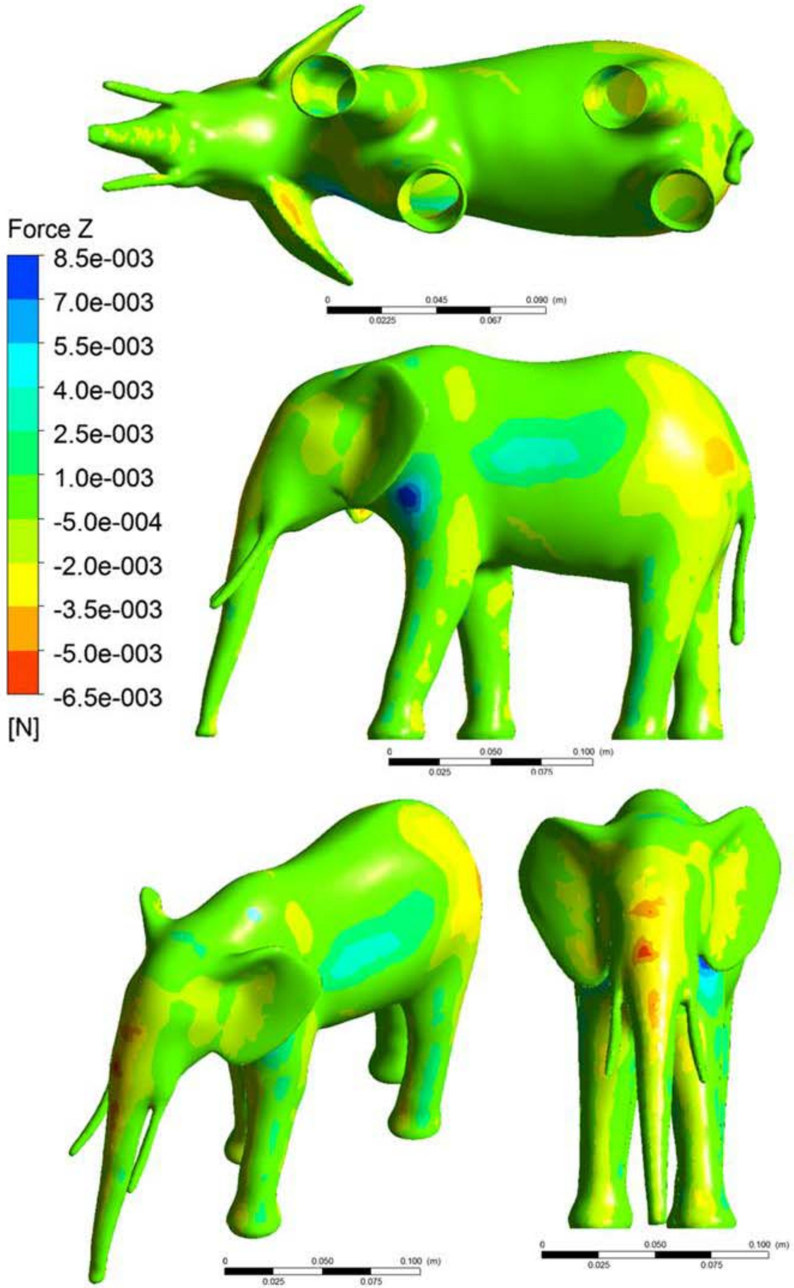
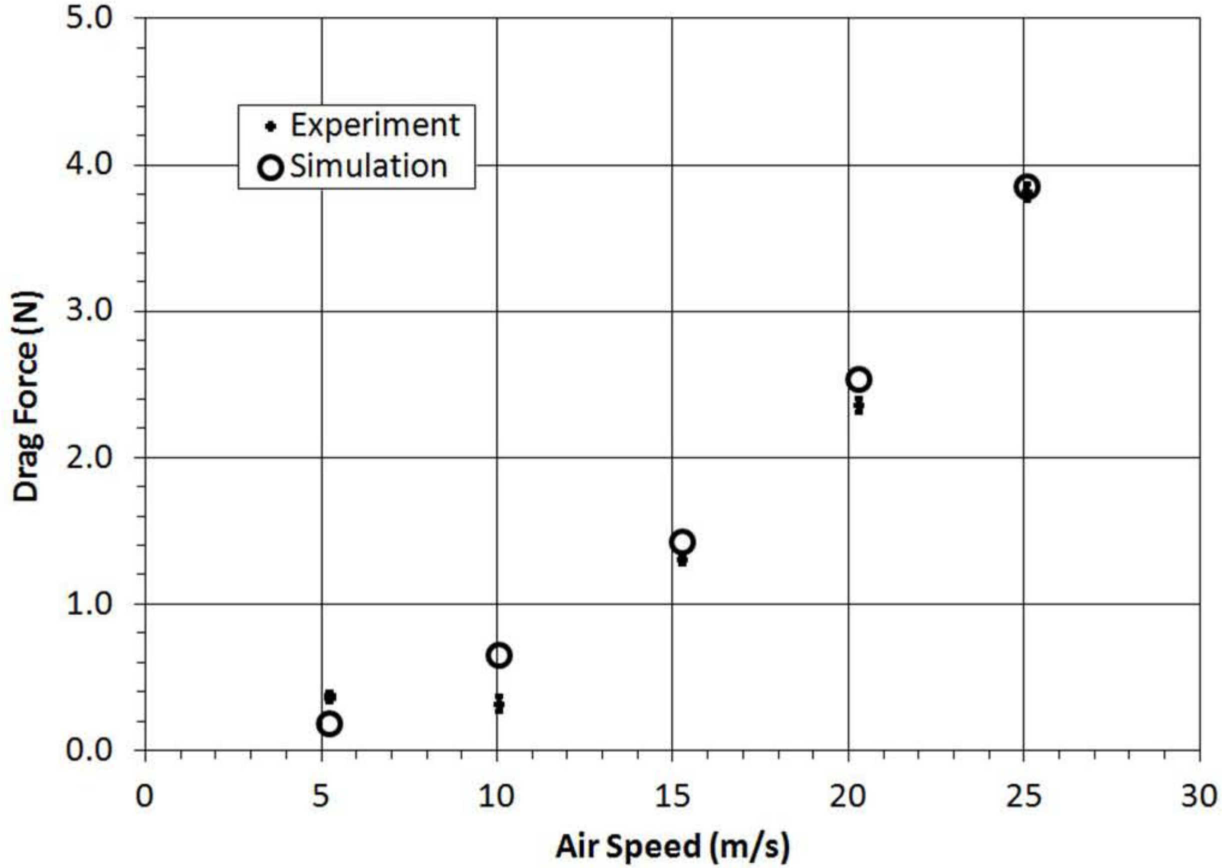
Testing computational fluid dynamics (in ANSIS Fluent)

Consider a non-spherical elephant…

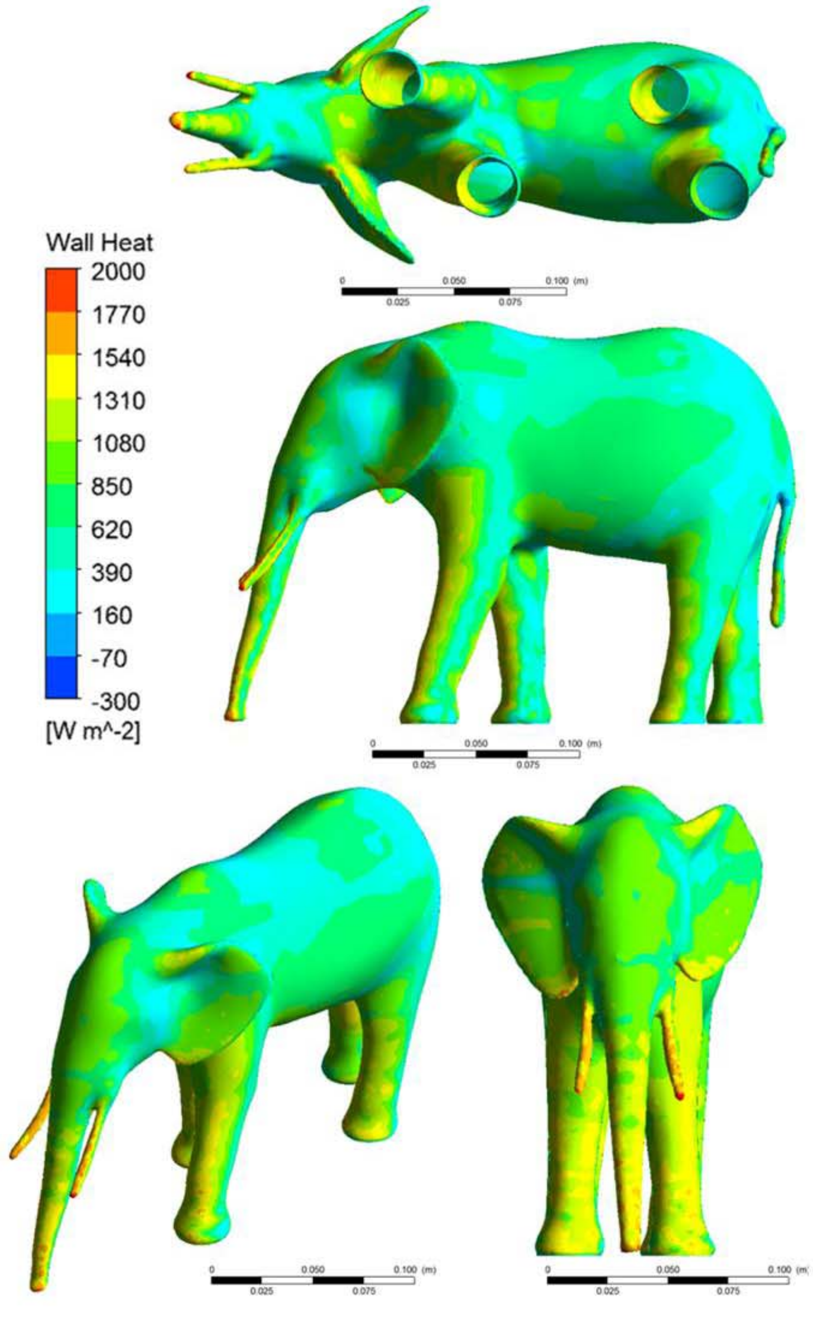
Momentum balance



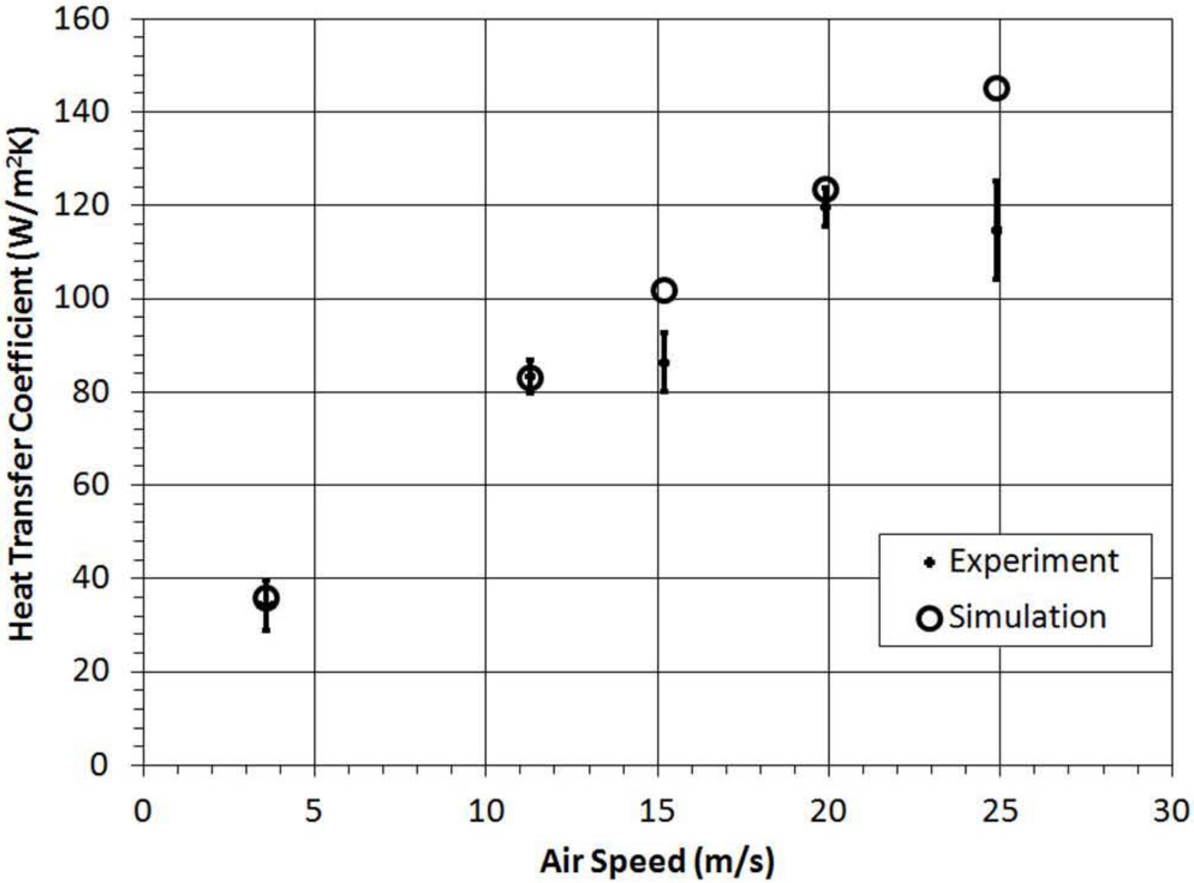
Calculated vs. experimental drag on a model elephant



Heat energy balance



Calculated vs. experimental elephant heat transfer coefficient



What are the properties of leatherbacks relevant to creating animated models at sea and on land?

Constantly swimming

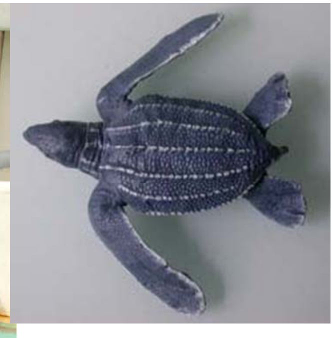
>1200 m Dive depth Capability

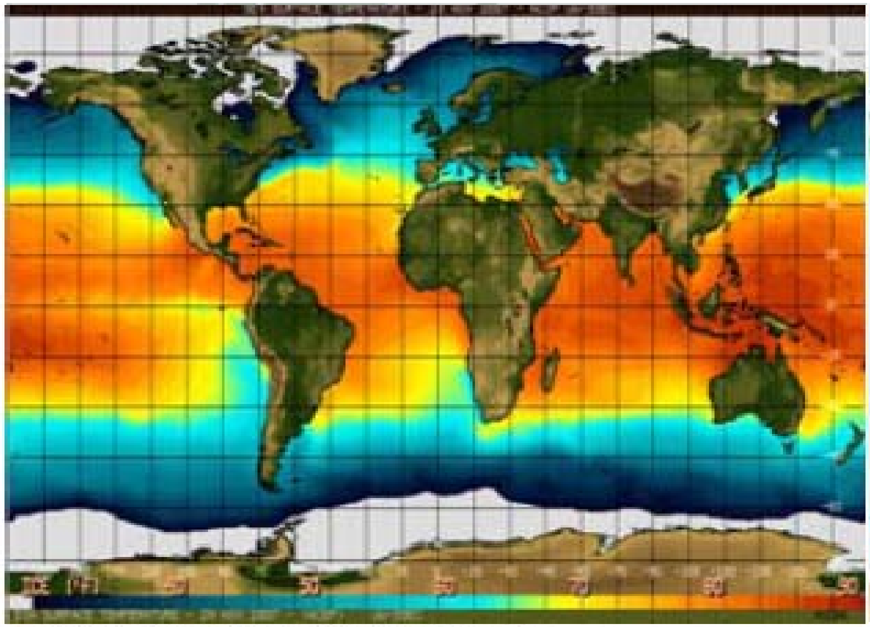
Up to 1 hour dives

3000 mile migrations

Jellyfish diet exclusively

9% protein
91% water





Temperature affects energetics and distribution for each life stage

How can we make the connections between

Global climate change

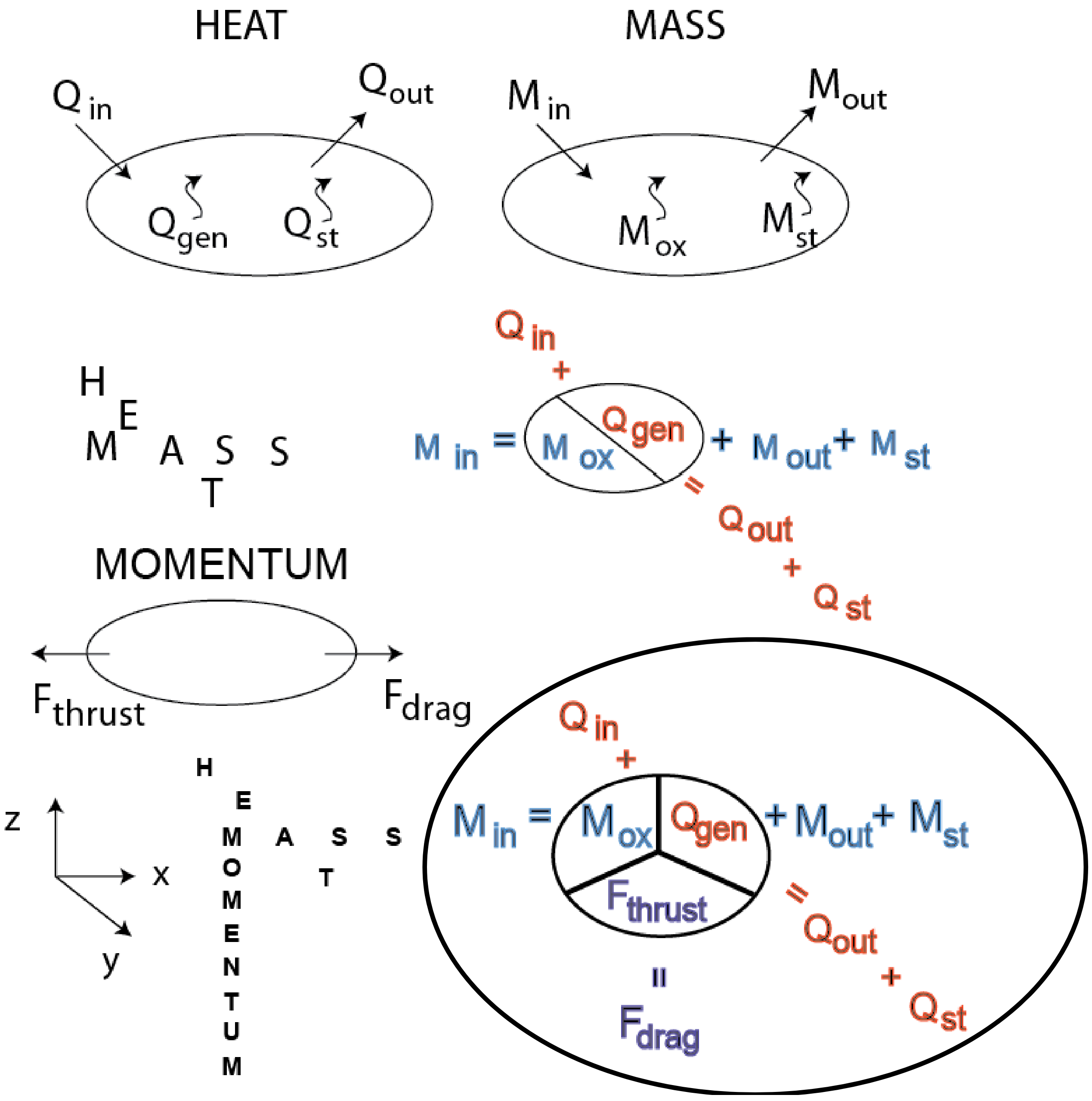
Local environments

Animal design

Physiological and behavioral properties?

We start by drawing pictures…

Aquatic
Climate change and Physiology

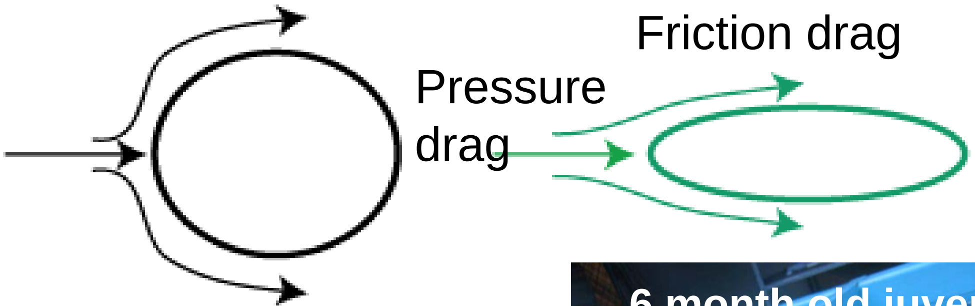


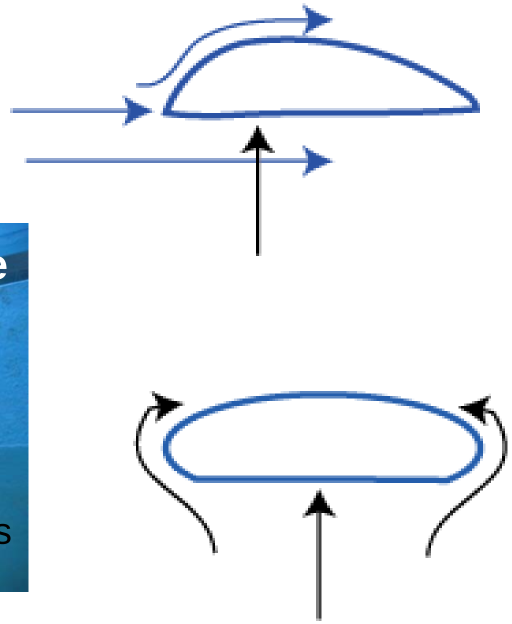
Body shape and (lipid) buoyancy changes in time and space: compensation mechanisms

Pre-migratory photo from Michael James' leatherbacks in Labrador. No channels.

Nesting leatherback sea turtle. Note the deep back channels. More surface area..more drag?

Flat bellied hatchling



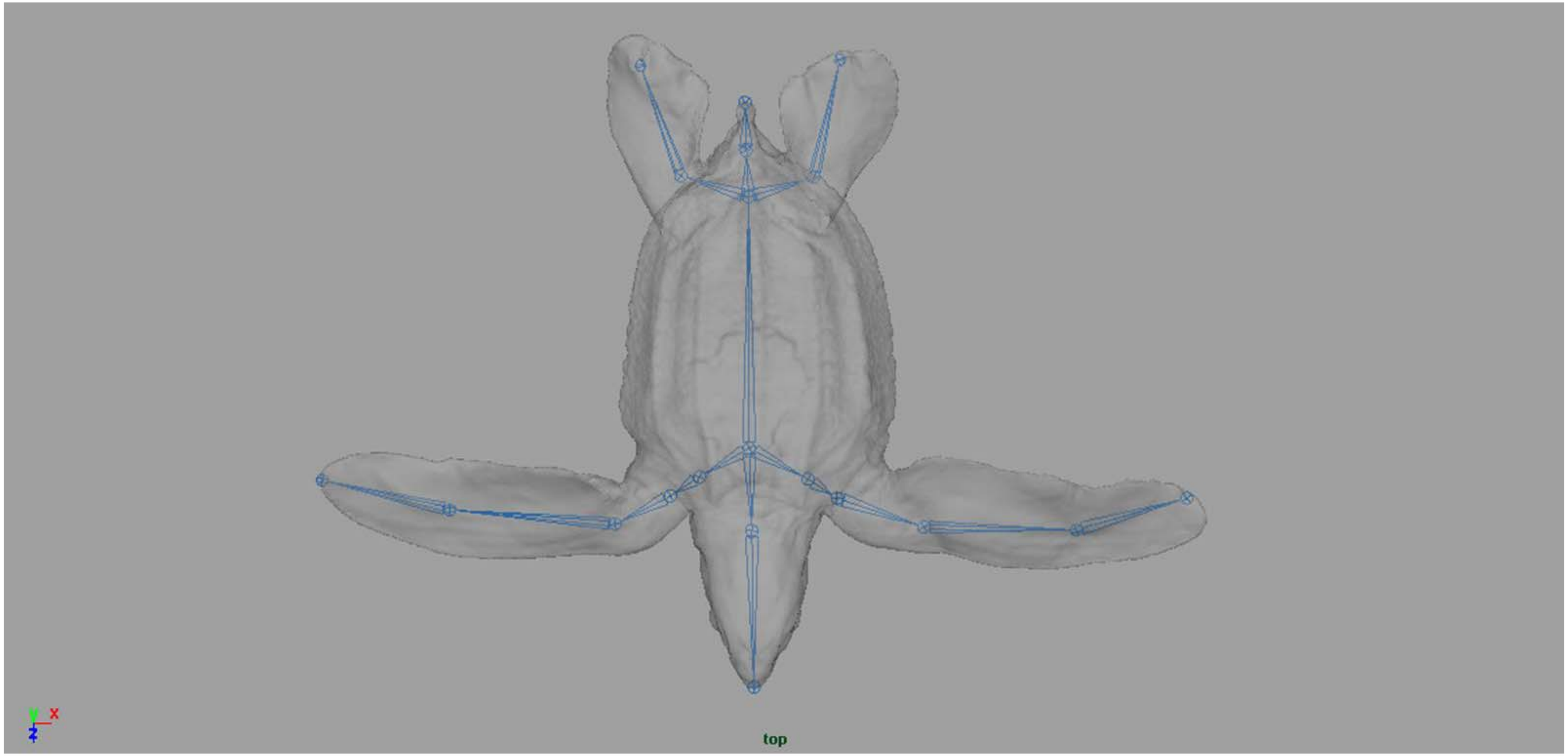


side

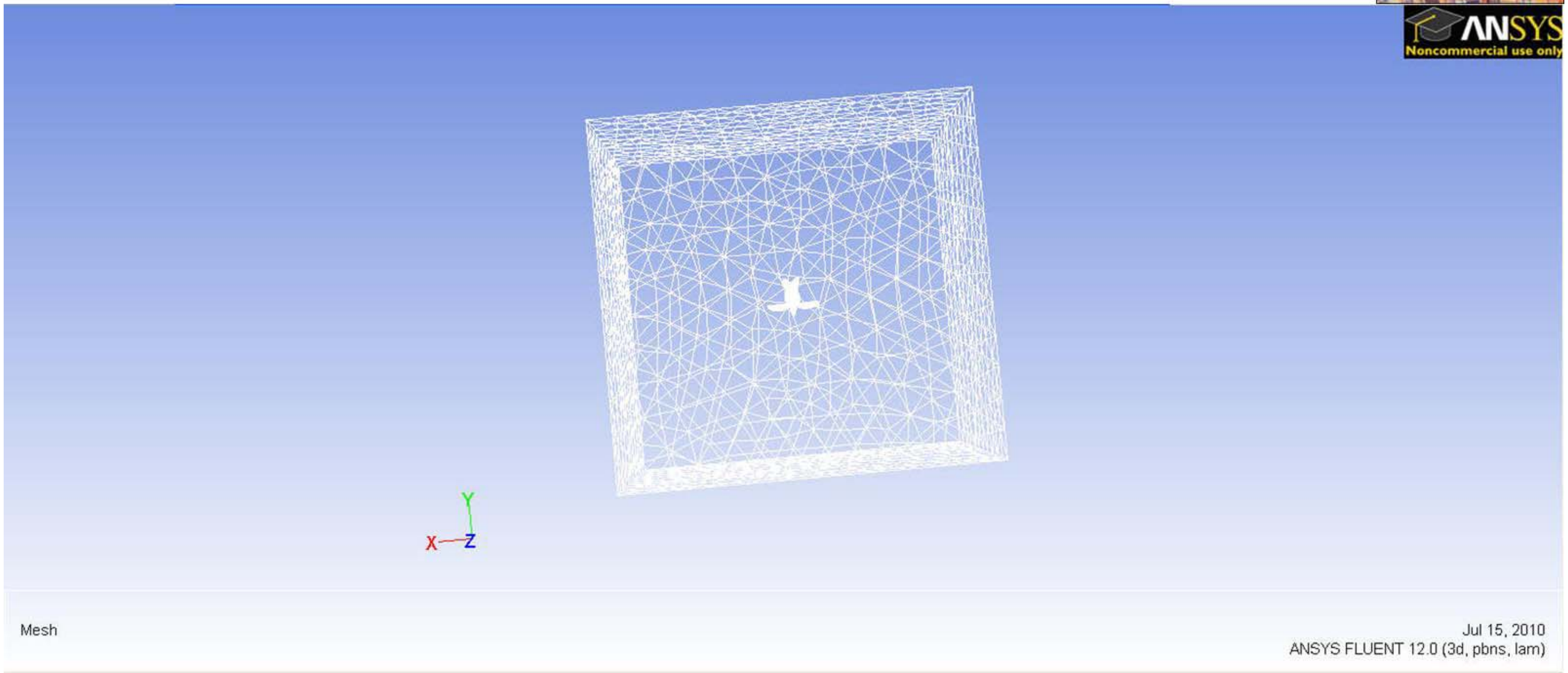
front

Creating a 3D virtual image from a casting, dead animal or photos drag calculations for different shapes.

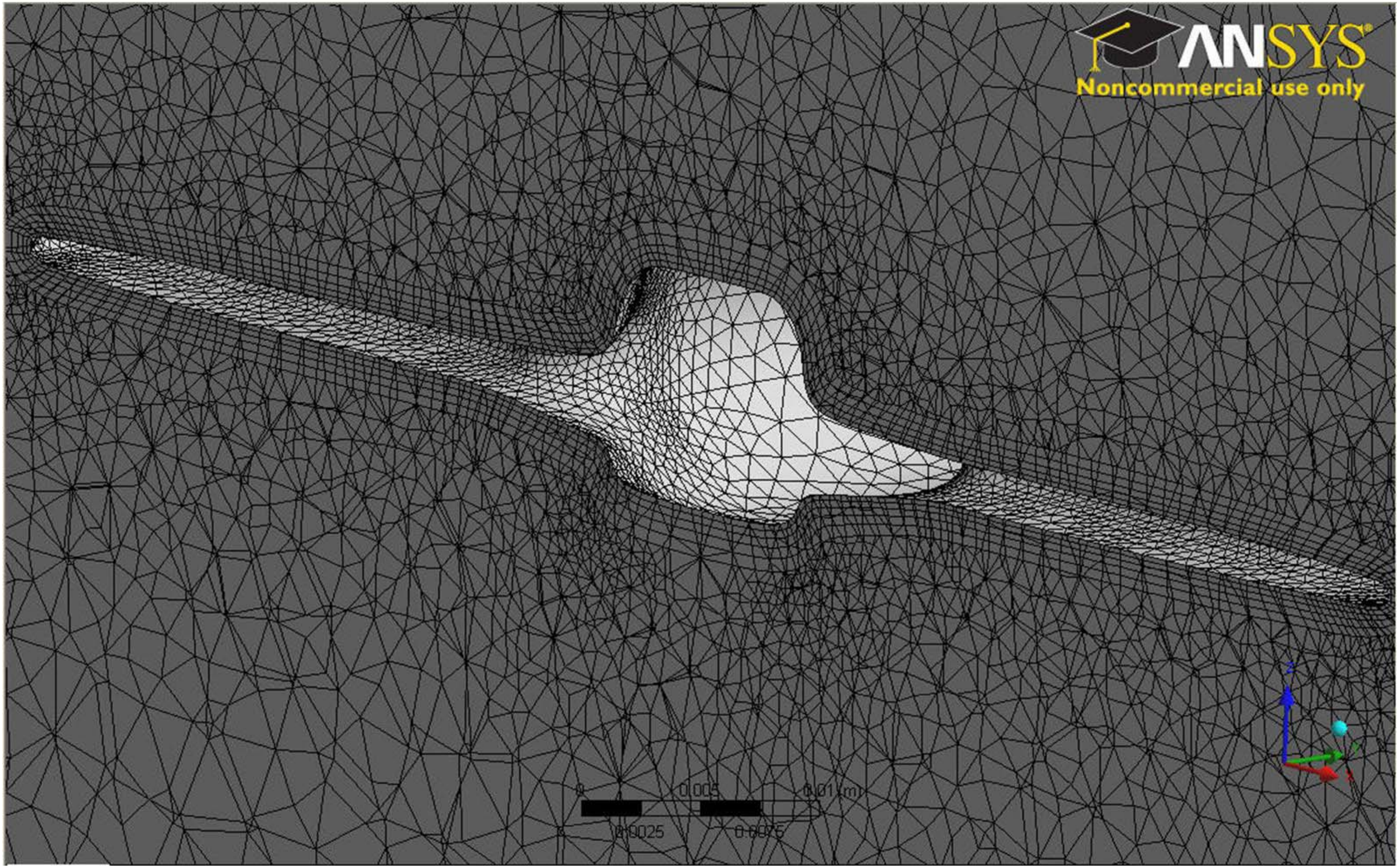
Draw in 3D or do mm resolution 3D laser scan, which connects the dots with a 3D mesh, then insert virtual skeleton, animate the limbs.



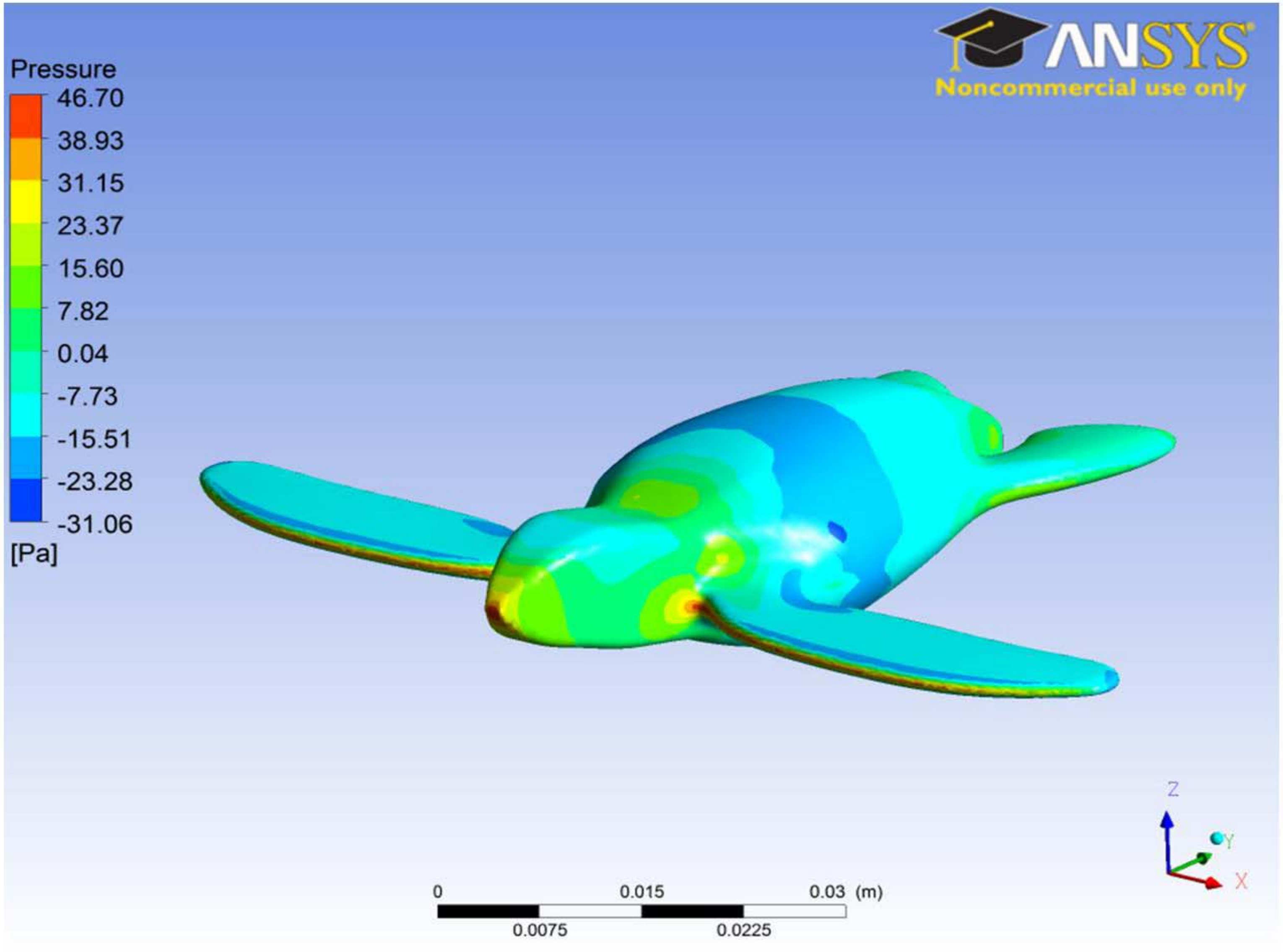
Solid body meshed to virtual water/wind tunnel in ANSYS Fluent computational fluid dynamics program in Computer Aided Engineering



Turtle boundary layer mesh connected to tunnel mesh

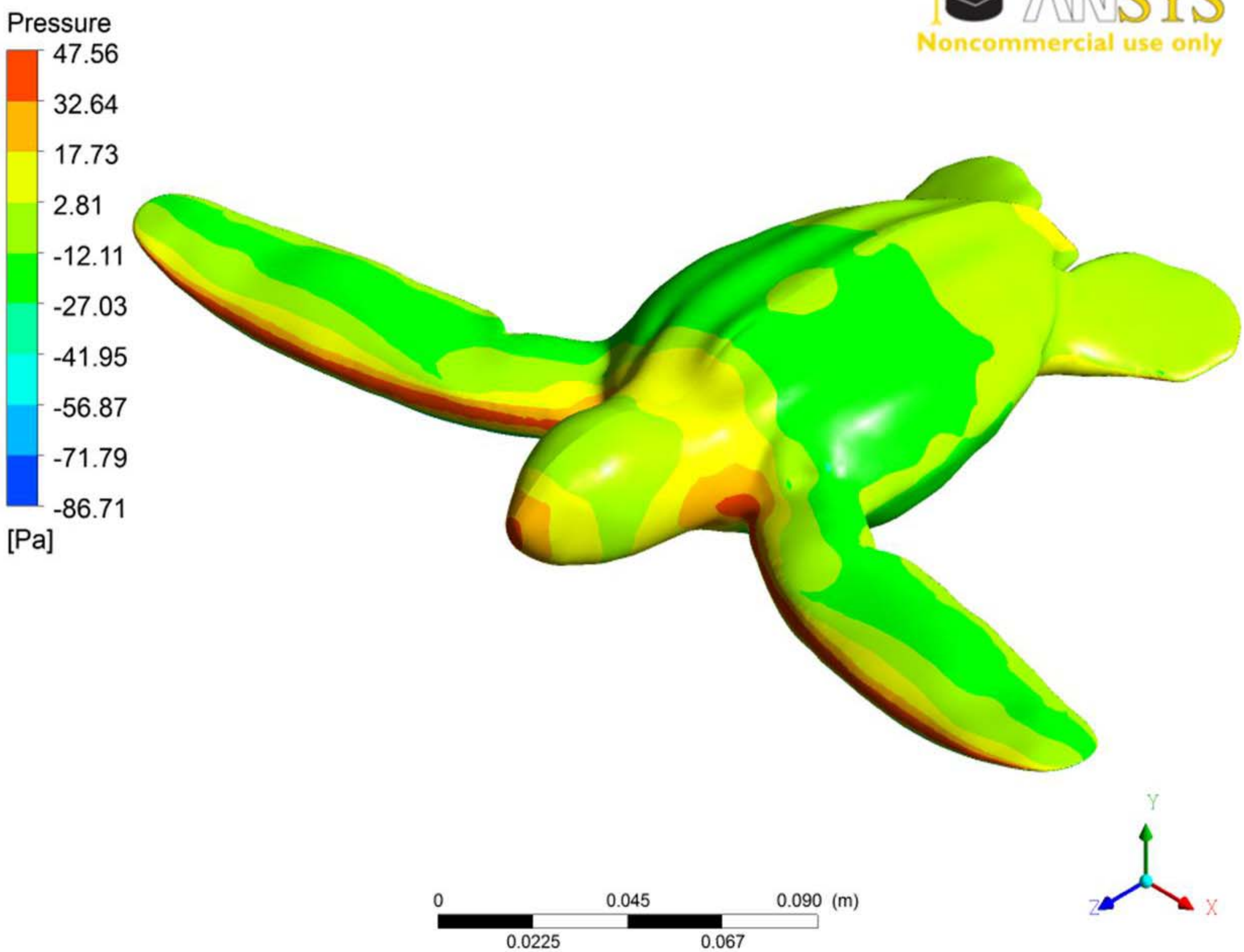


Static pressure contours (pascals) on turtle body

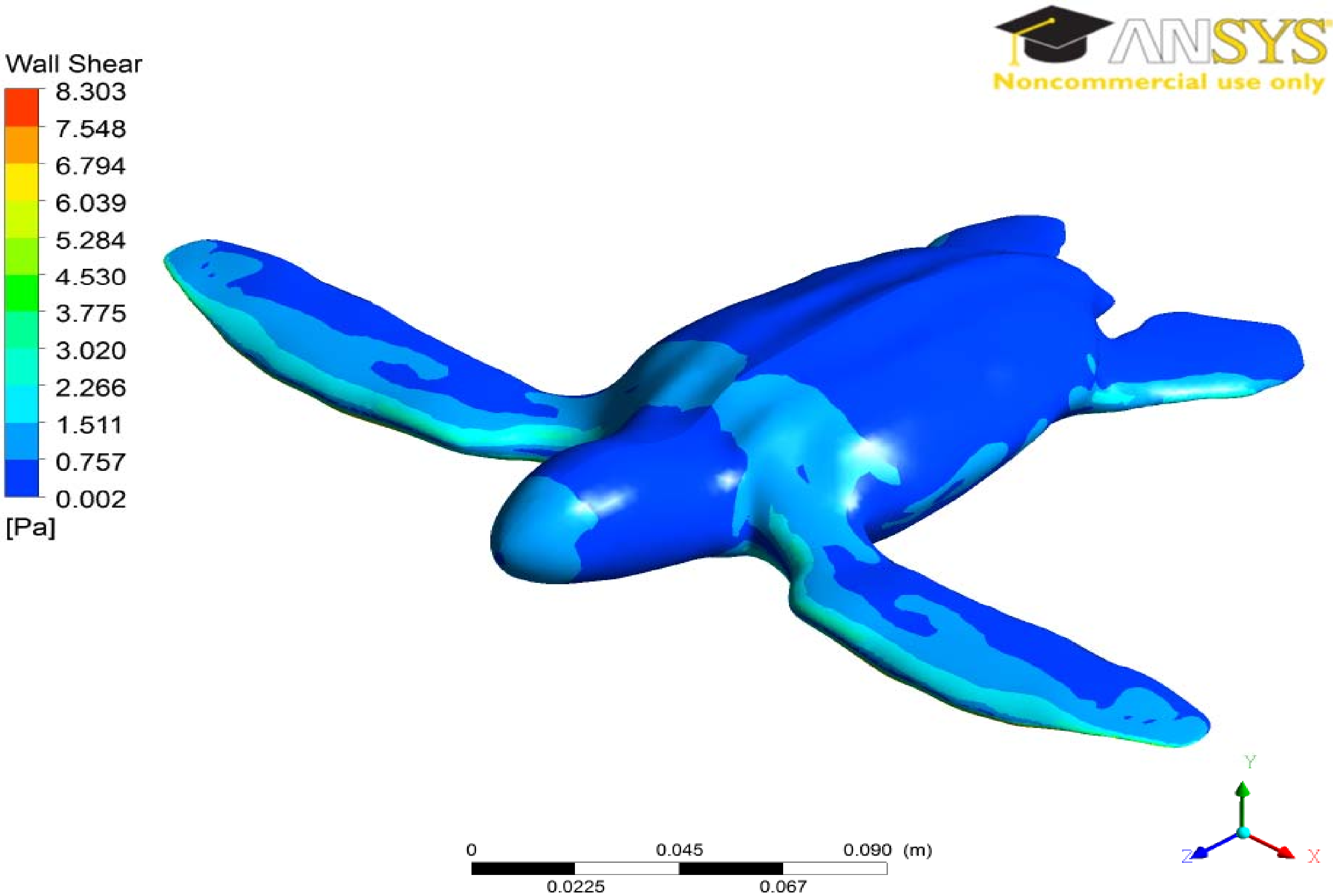


Static pressure contours allow calculation of pressure drag

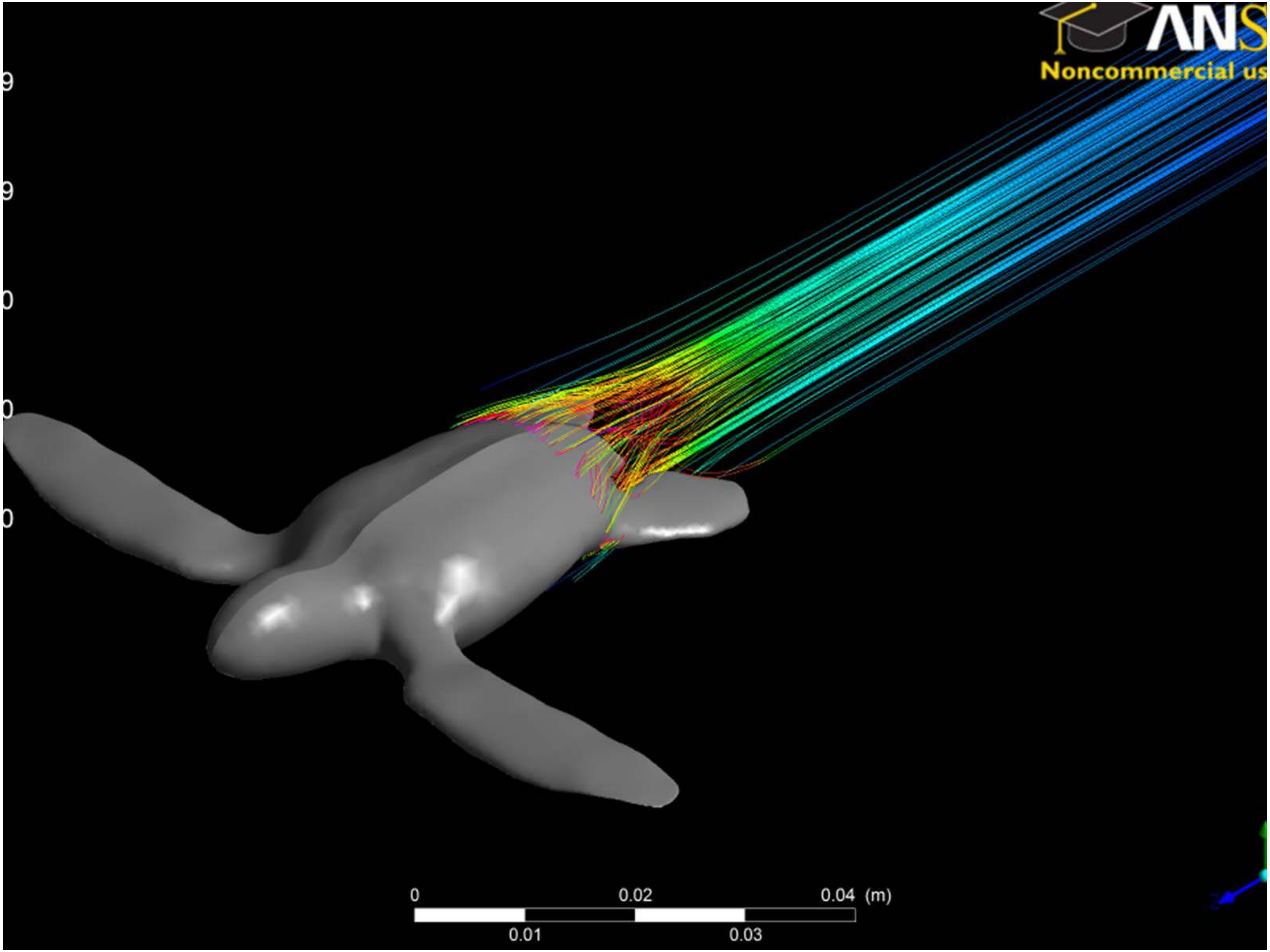
Static pressure contours (pascals) greater on turtle body at higher speeds



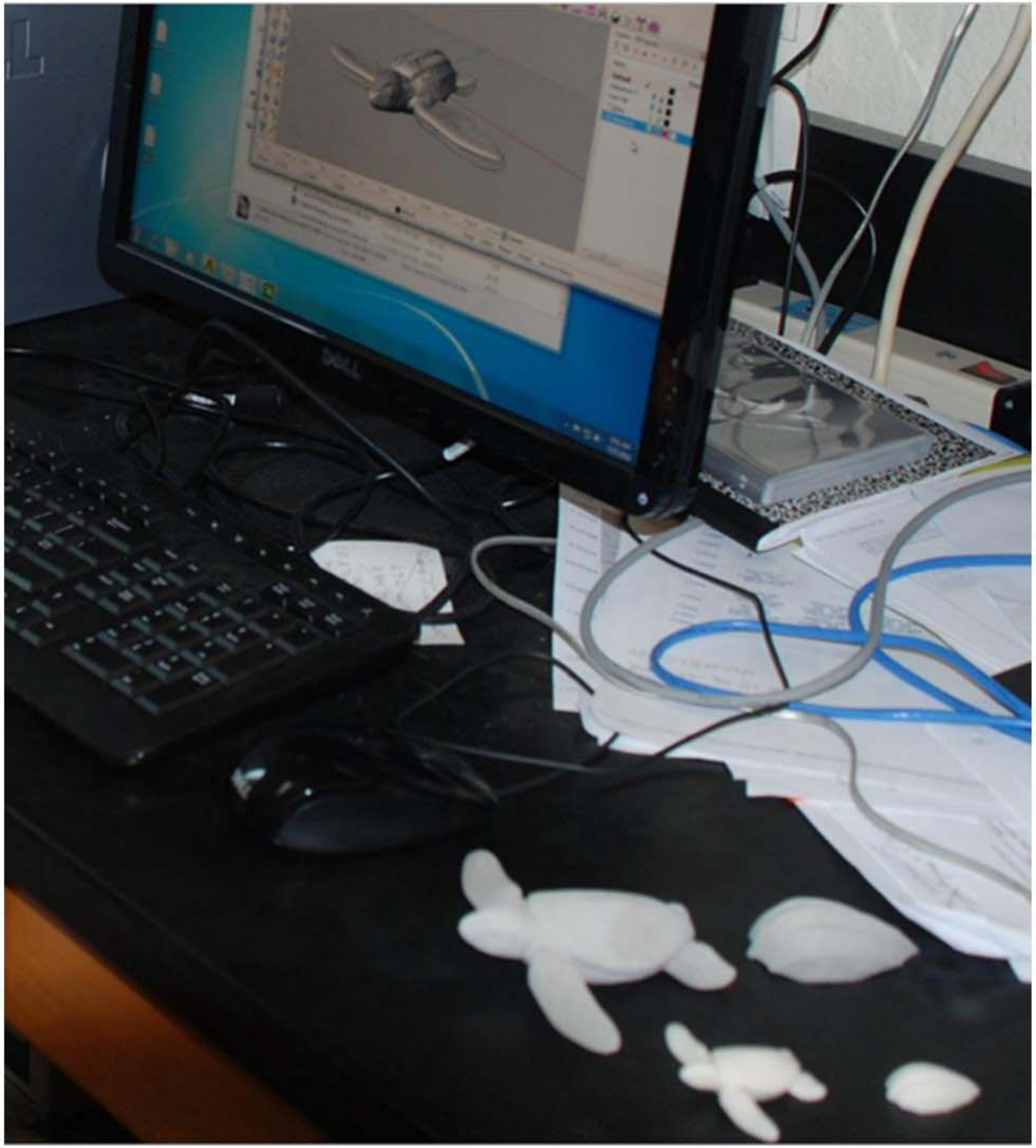
Pressure drag almost an order of magnitude greater than friction drag!



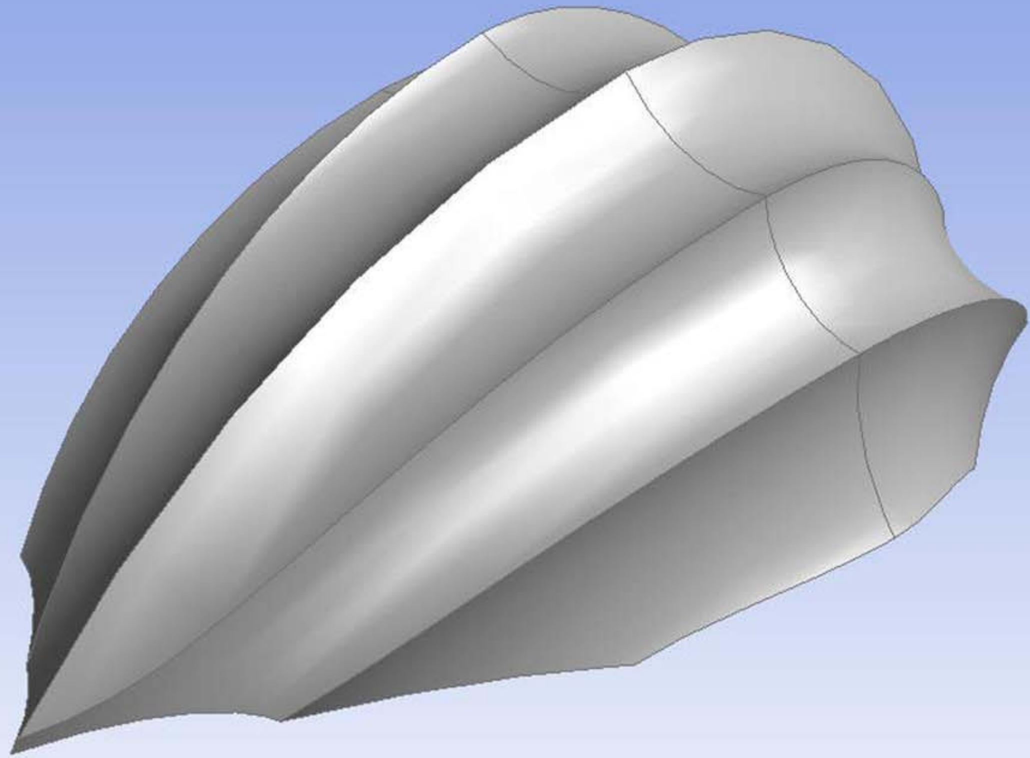
Velocity vectors (m/s) allow calculation of friction (shear) drag



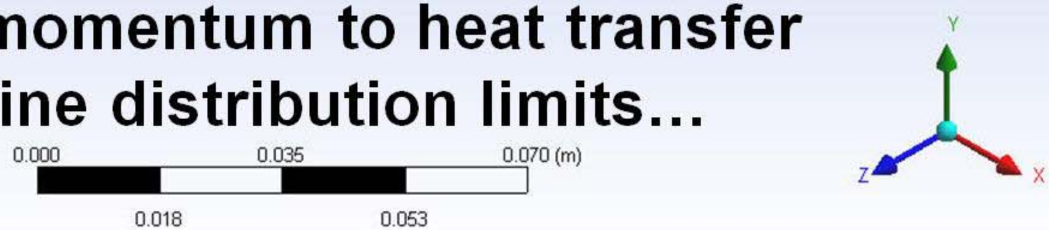
Noncommercial us
0
0.02
0.04 (m)
0.01
0.03



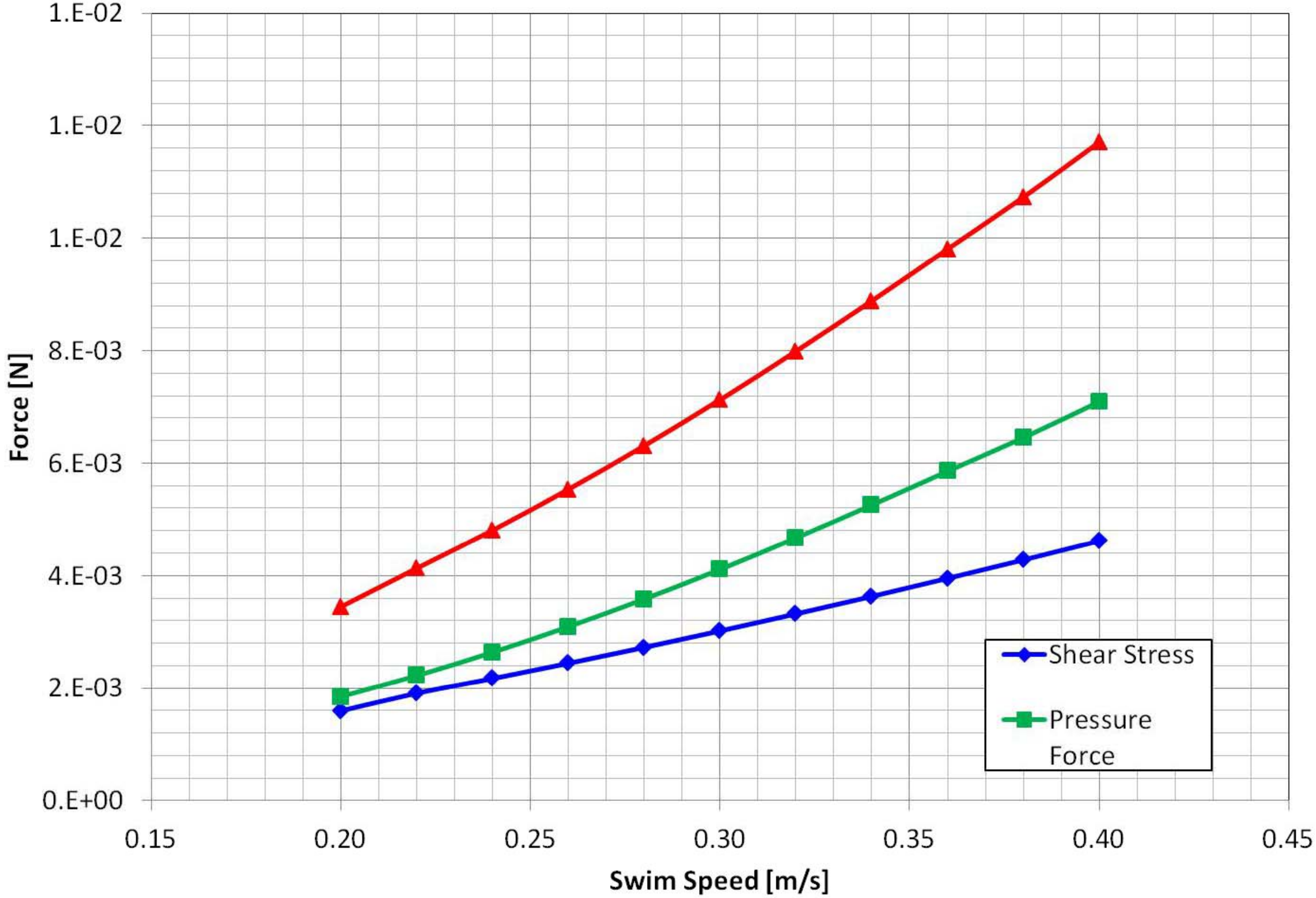
1) Flat bottom, curved top shell design has lift
2) Long channels prevent lateral, vertical flow.
3) Low friction drag relative to pressure drag allows for low cost surface area increase to create channels to minimize drag due to turbulent eddy formation as lipids depleted.



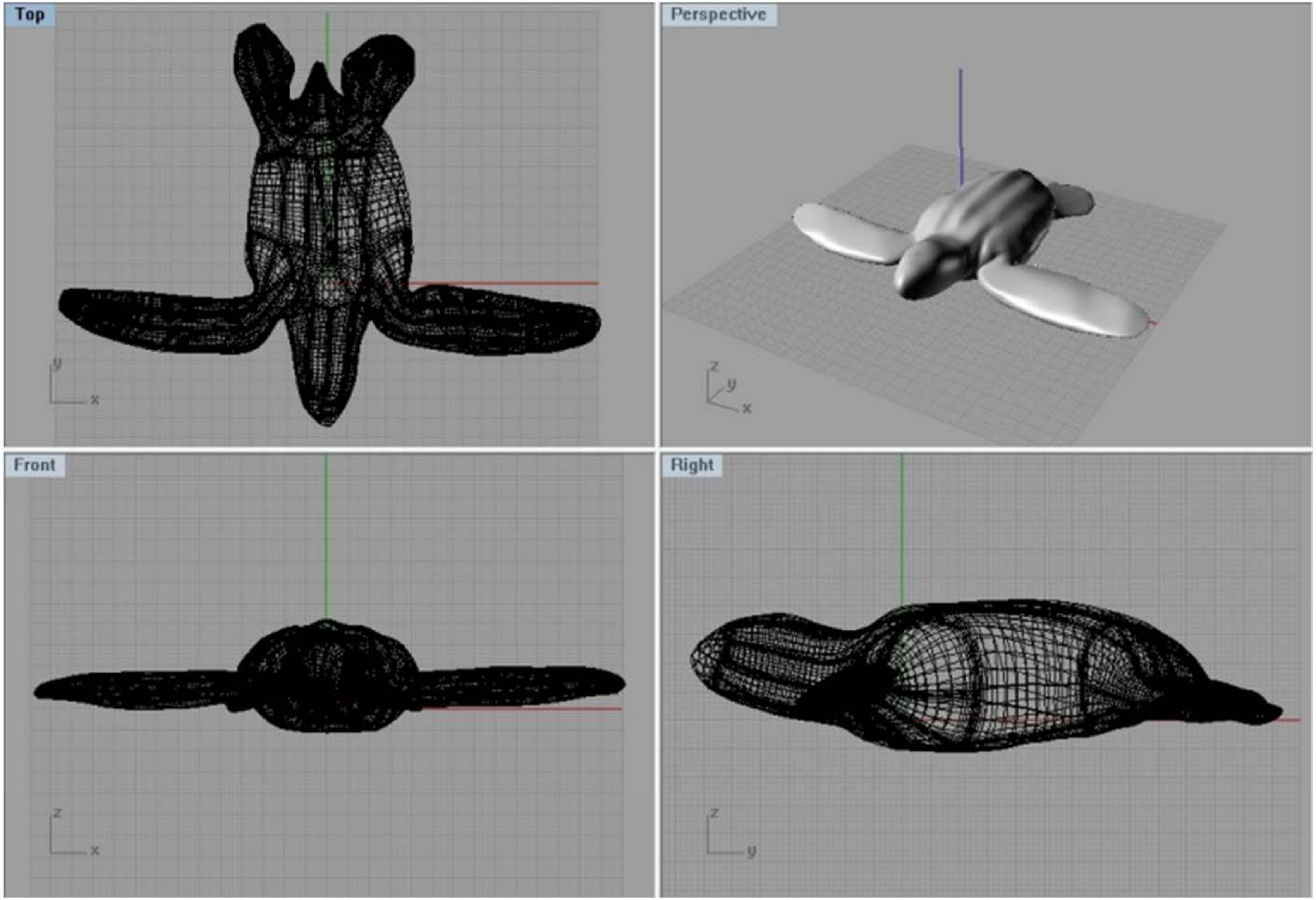
connecting momentum to heat transfer to determine distribution limits…



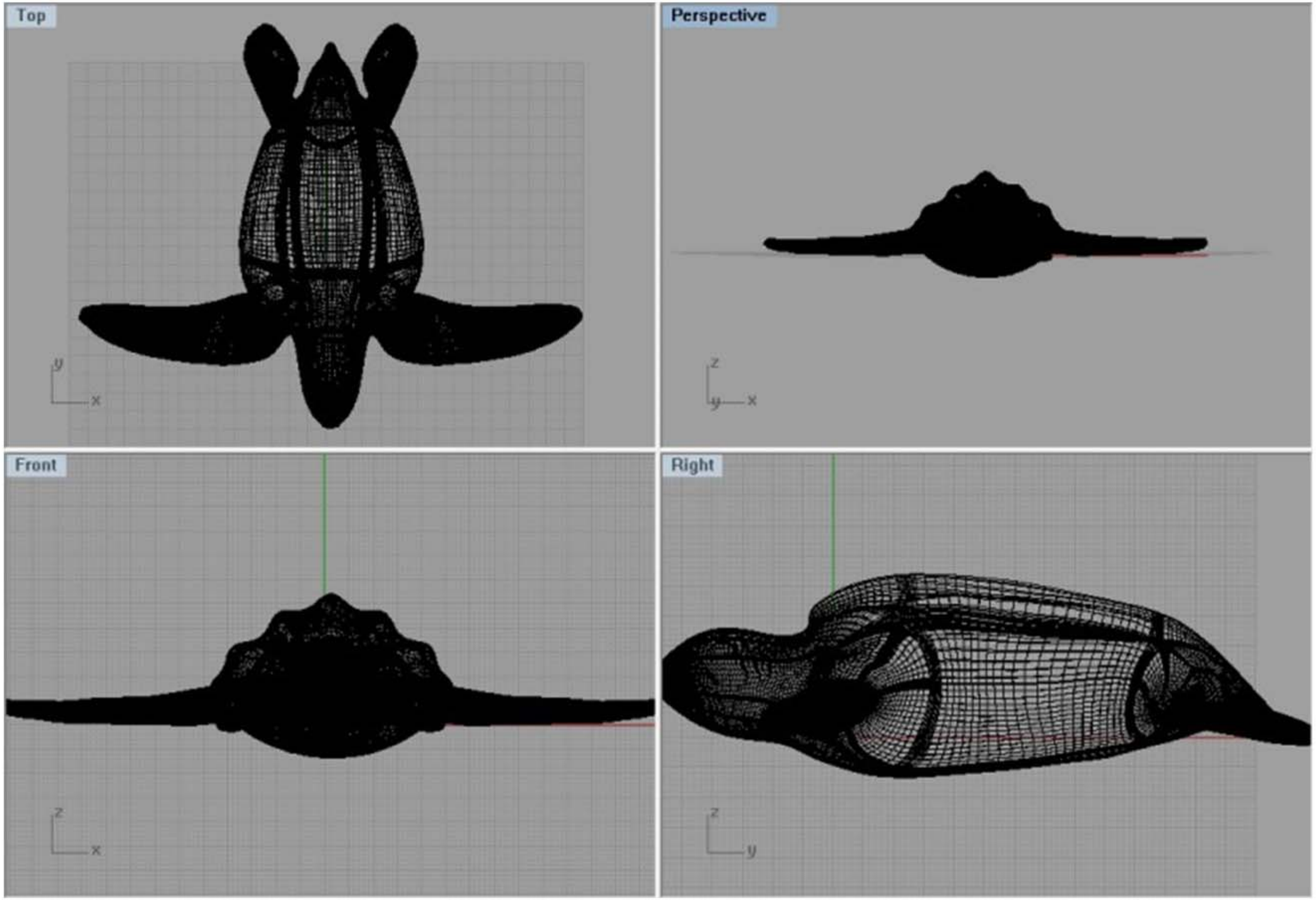
Intact Leatherback drag forces (CFD)



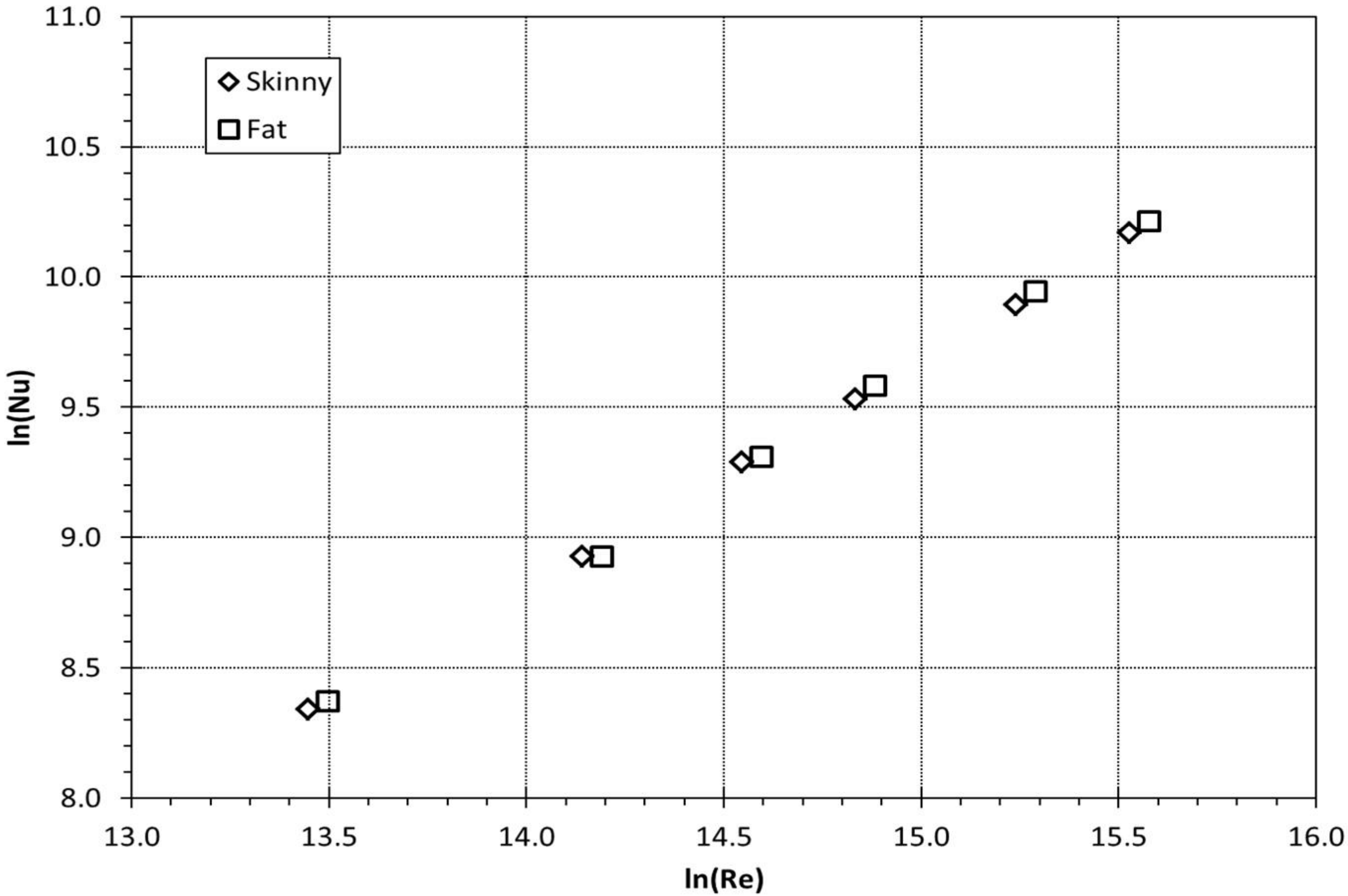
‘Fat’ turtle

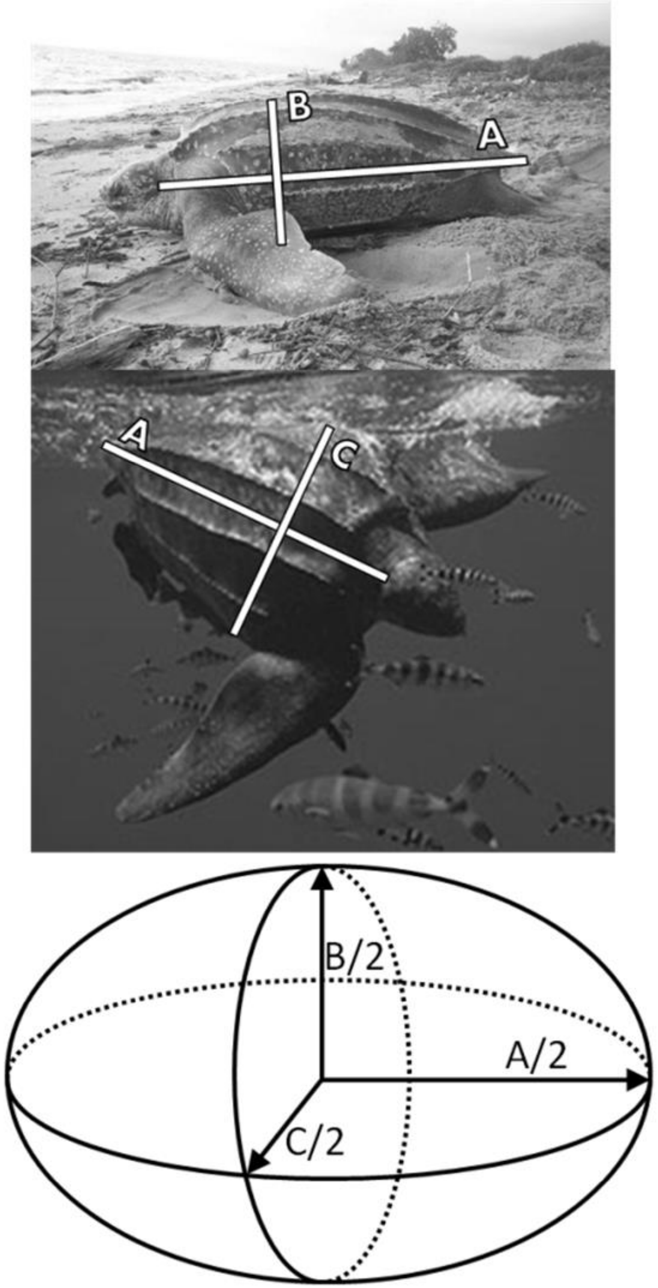


‘Skinny’ turtle

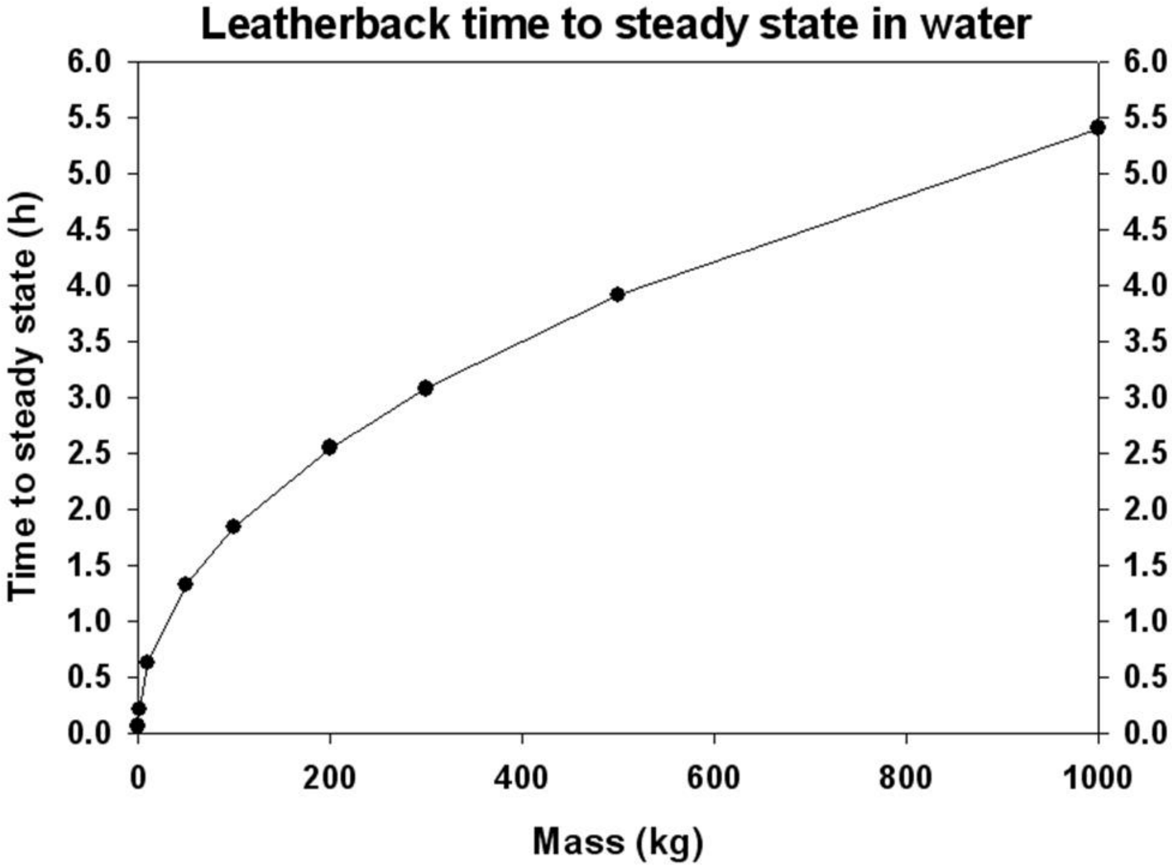


Nusselt number vs. Reynolds number (dimensionless heat transfer vs. velocity) for skinny vs. fat morphology (CFD).



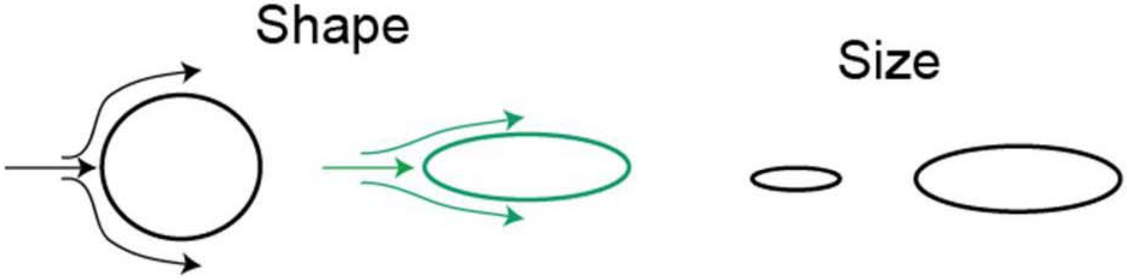

B
A
A
C
B/2
A/2
C/2

Can we do a steady state analysis to get a first approximation for water temperatures they need to get oceanic distribution limits?



Size and shape matter

Environmental constraints on distributions



$$T_c - T_s = \frac{q''' R^2}{6k} \qquad T_c - T_s = \frac{q''' S^2}{2k}$$

$$S^2 = \frac{a^2 b^2 c^2}{a^2 b^2 + a^2 c^2 + b^2 c^2} = \frac{1}{3} \quad \text{for sphere of } R = 1$$

$$q''' = \frac{Q_{gen}}{V}$$

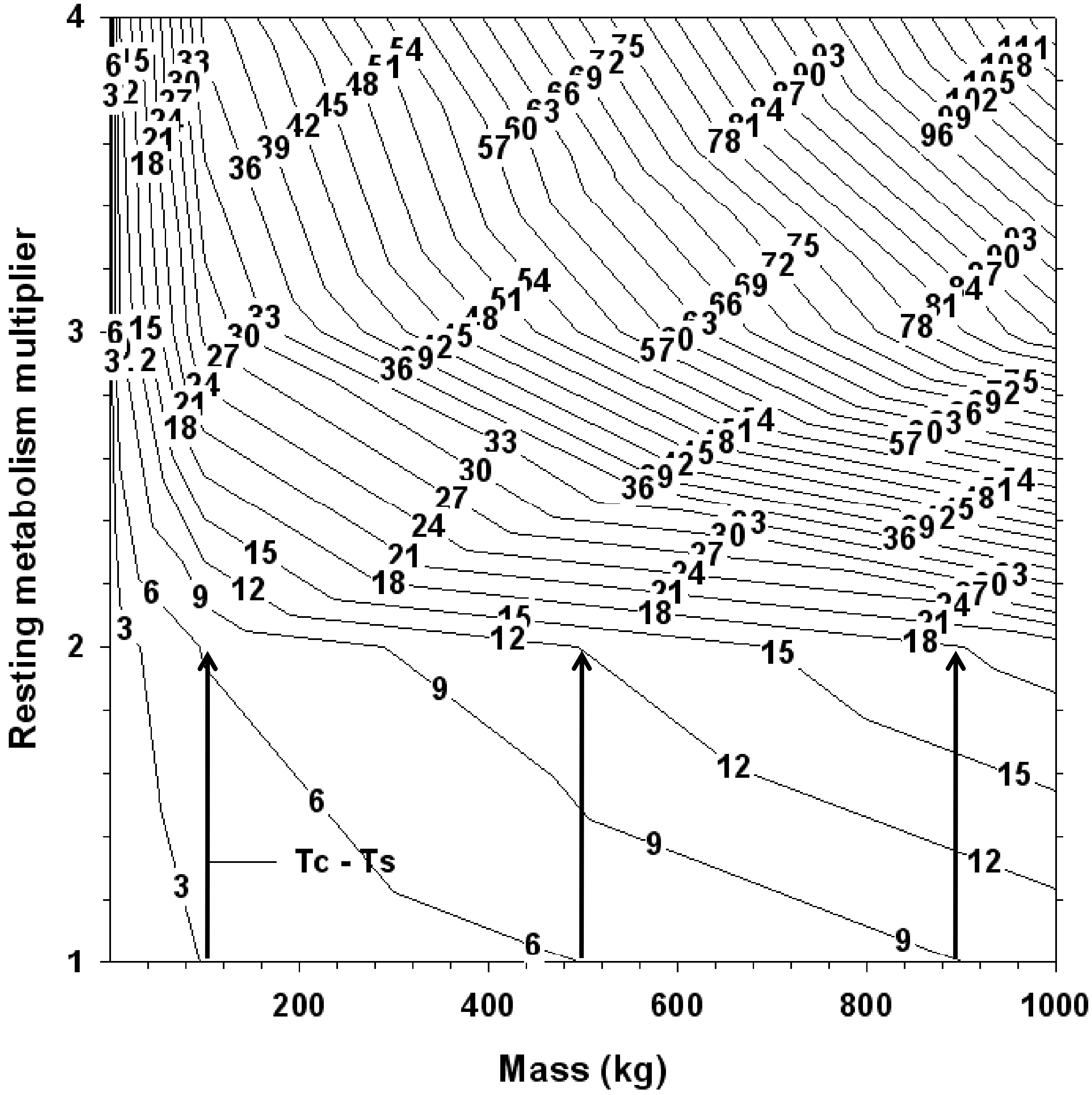
drag ← **CFD** (→ h_c, A)

In water $Q_{gen} = Q_{out} = Q_{conv} = h_c A(T_s - T_w)$

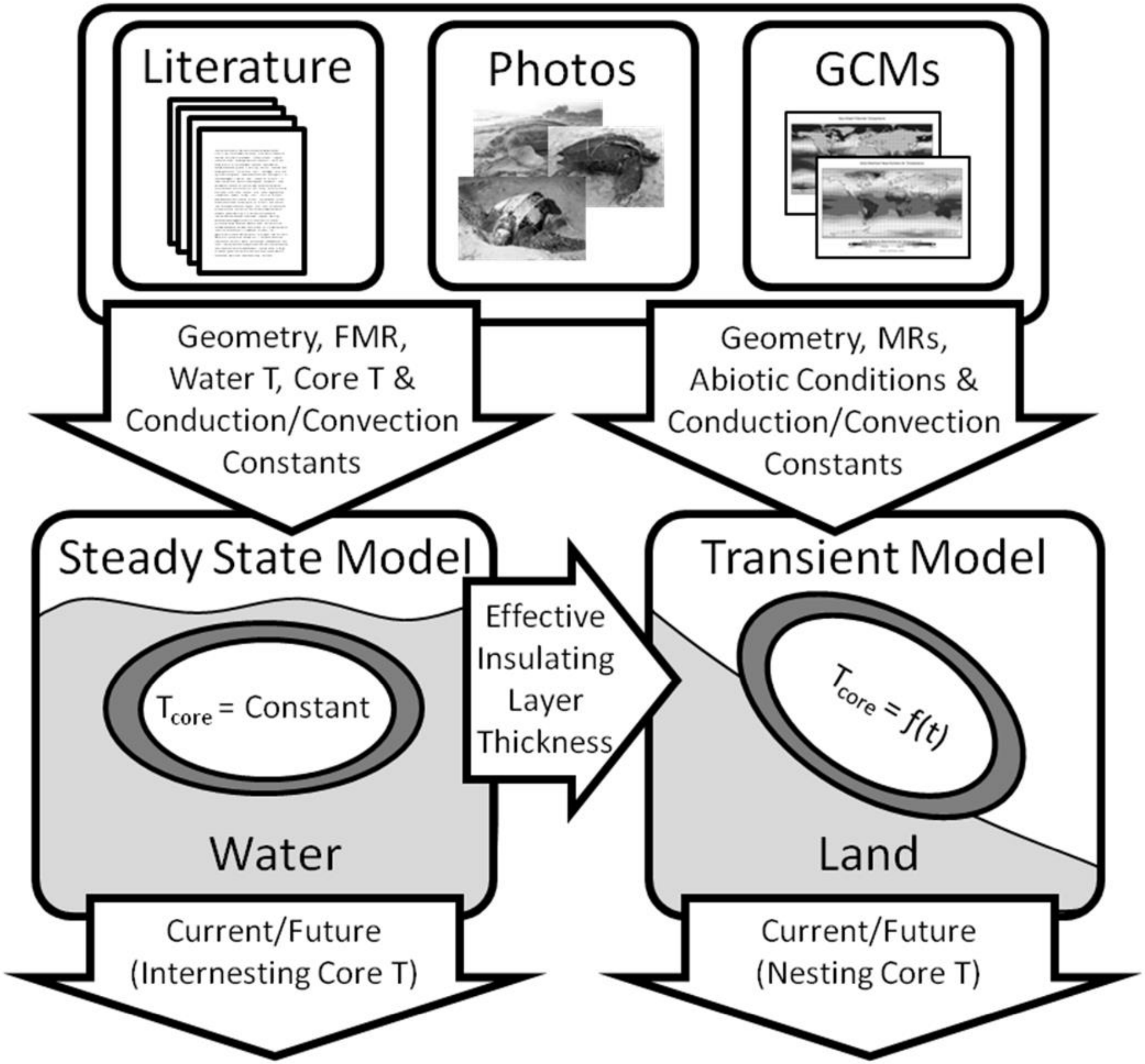
Getting requisite water temperature requirement:

$$T_w = T_c - Q_{gen} \left[\frac{S^2}{2kV} - \frac{1}{h_c A} \right]$$

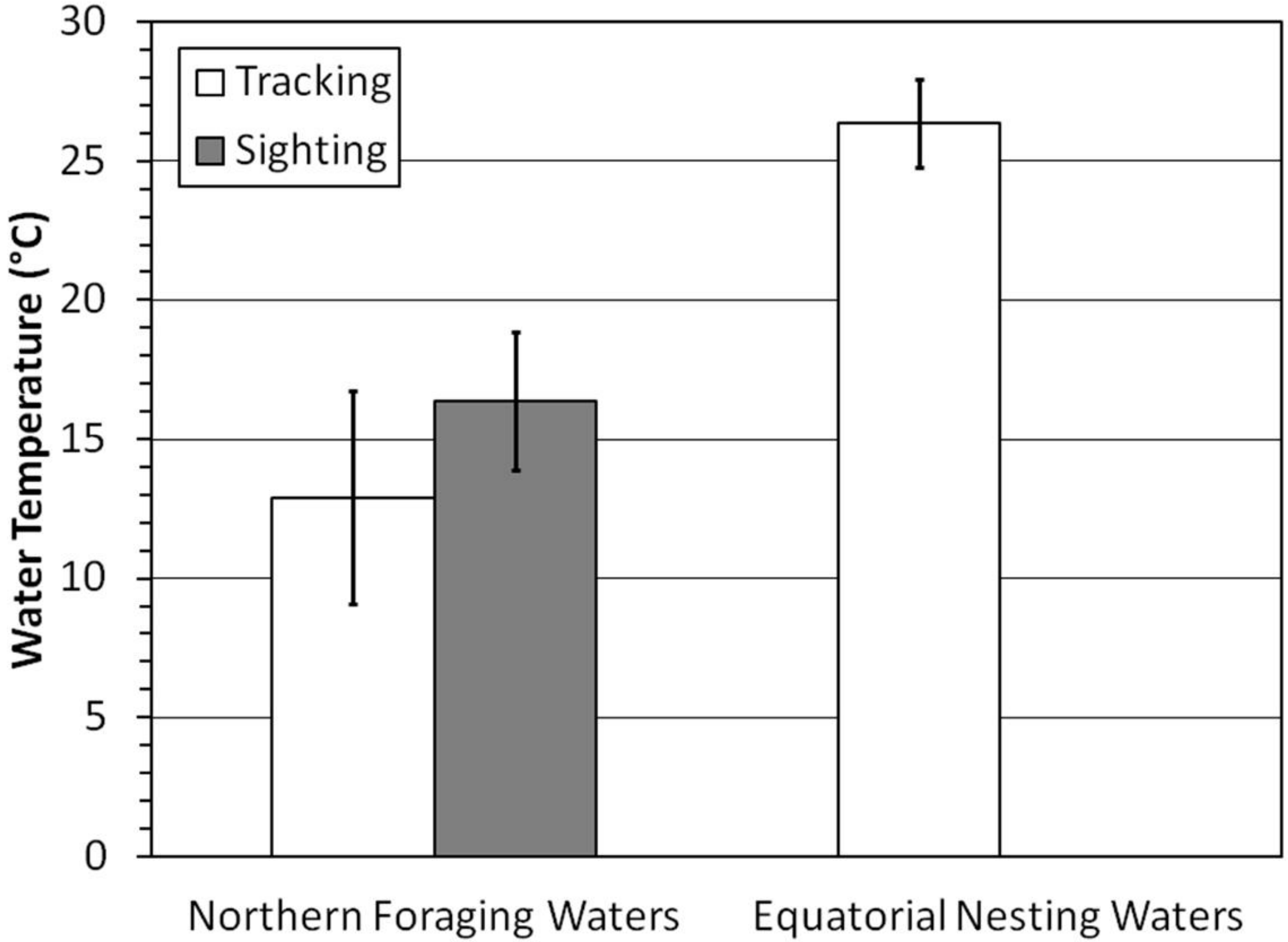
Leatherback T_{core} - T_{skin} for different activity levels



A schematic diagram of the leatherback models

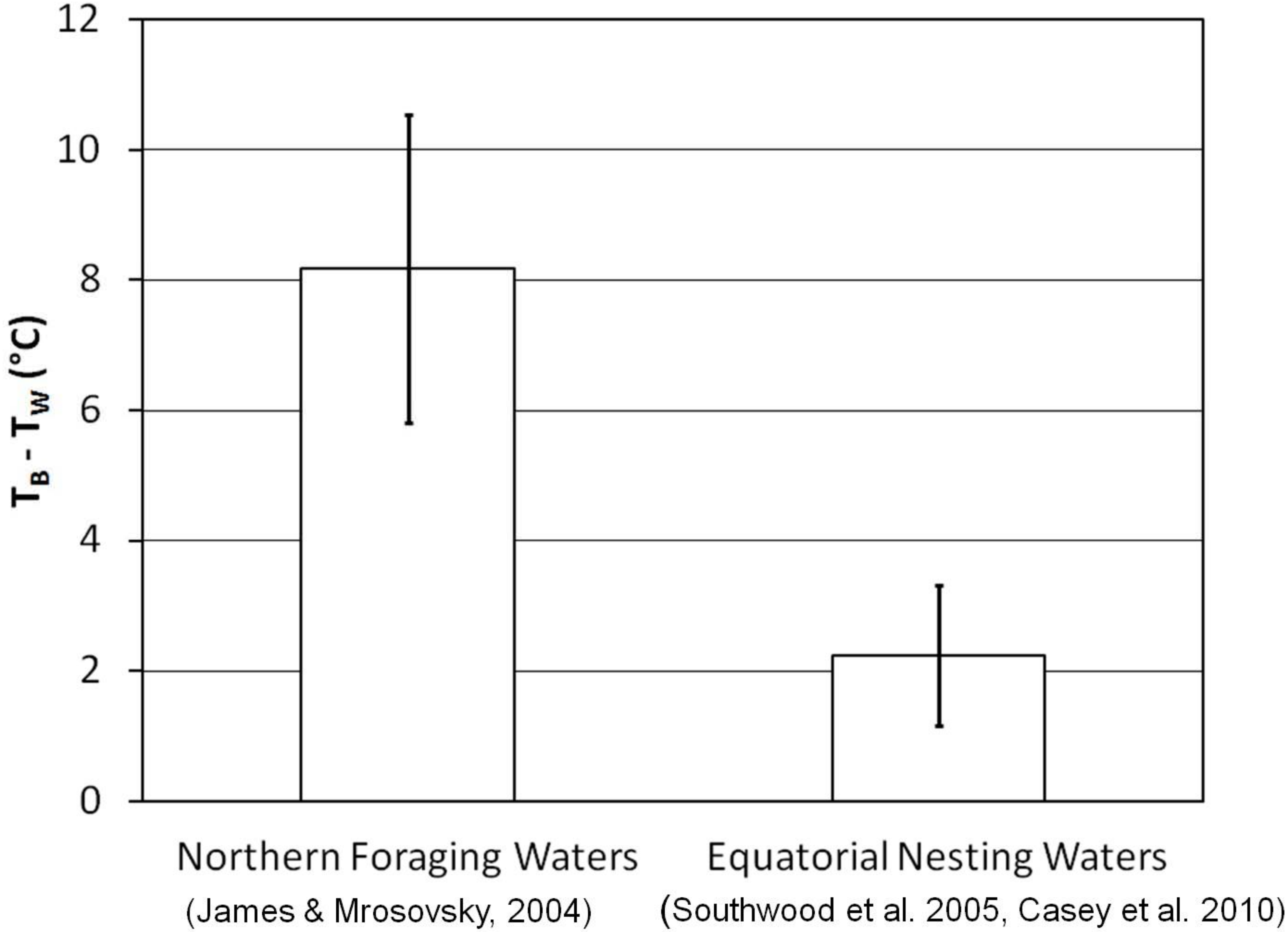


The ambient water temperature leatherbacks experience while in their foraging and nesting waters.

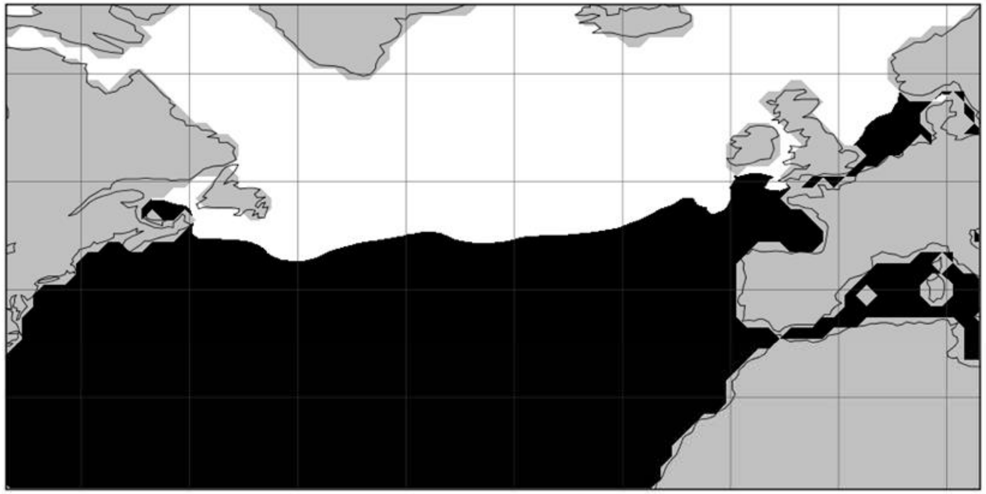


Goff & Lien 1988, James & Mrosovsky 2004, James, Davenport, et al. 2006, McMahon & Hays 2006, James, Sherrill-Mix, et al. 2006, James et al. 2007), Southwood et al. 1999, 2005, James, Davenport, et al. 2006, Sherrill-Mix et al. 2007, Shillinger et al. 2008

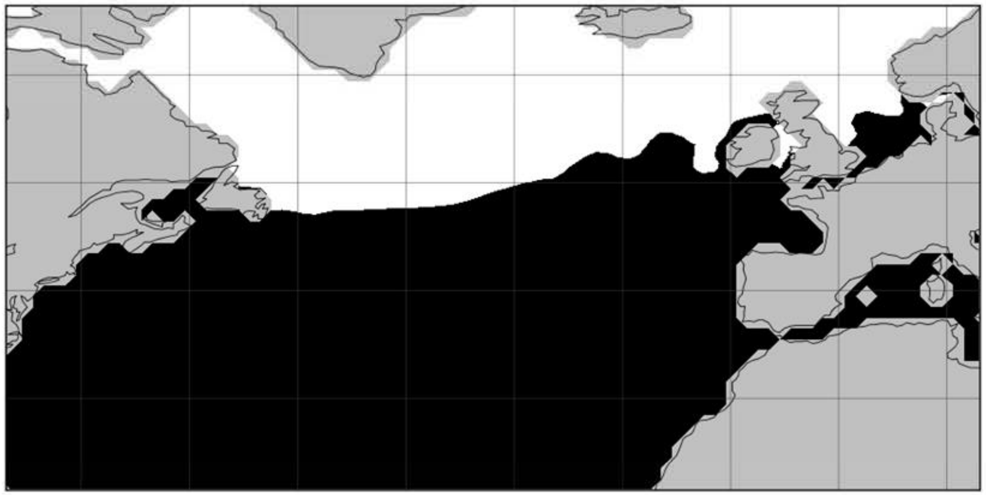
The difference between deep body temperature and water temperature.



The boundary between black and white is the 16 °C isotherm for the most active foraging month in the North Atlantic. The line moves approximately 3.5° north along the western Atlantic coast and 4.5 ° along the eastern coast.

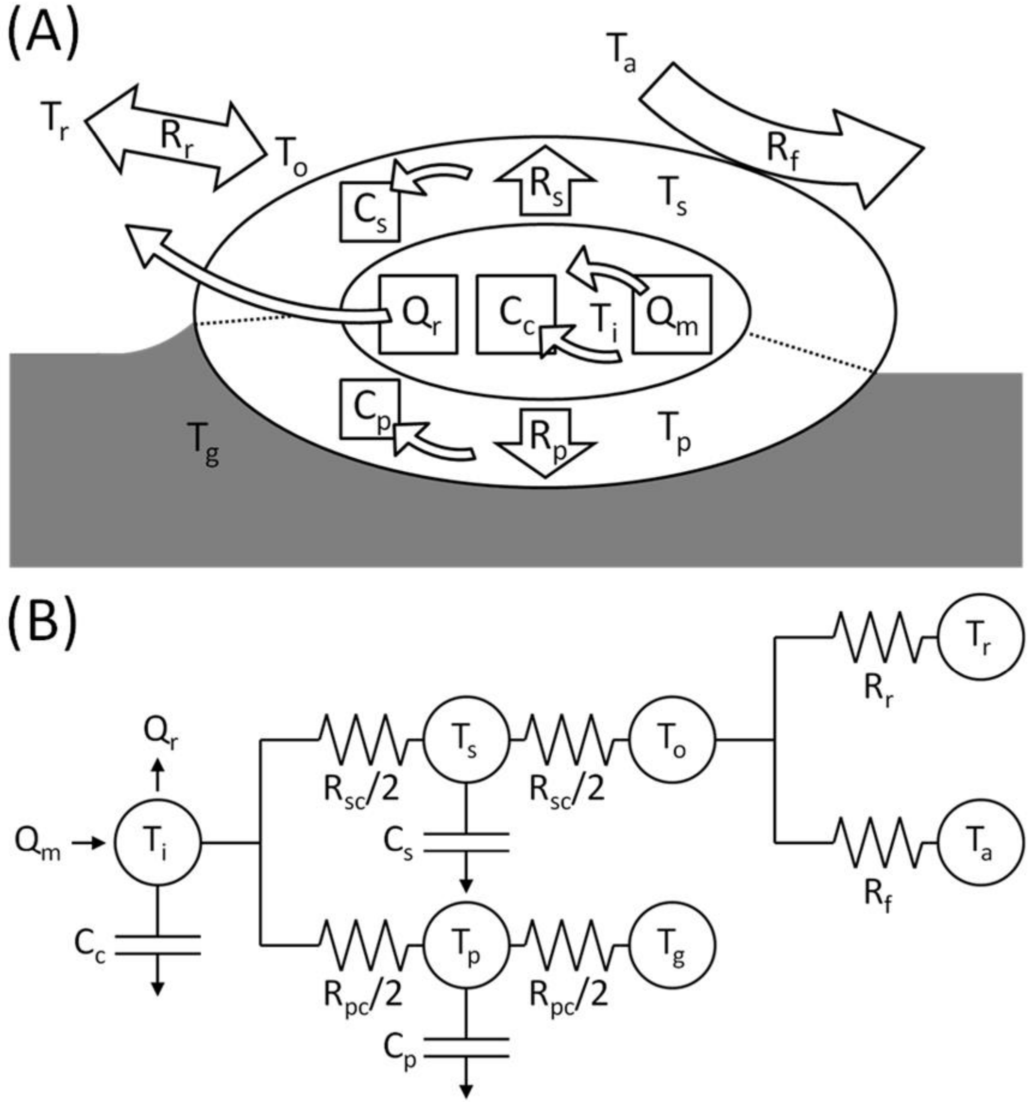


Present

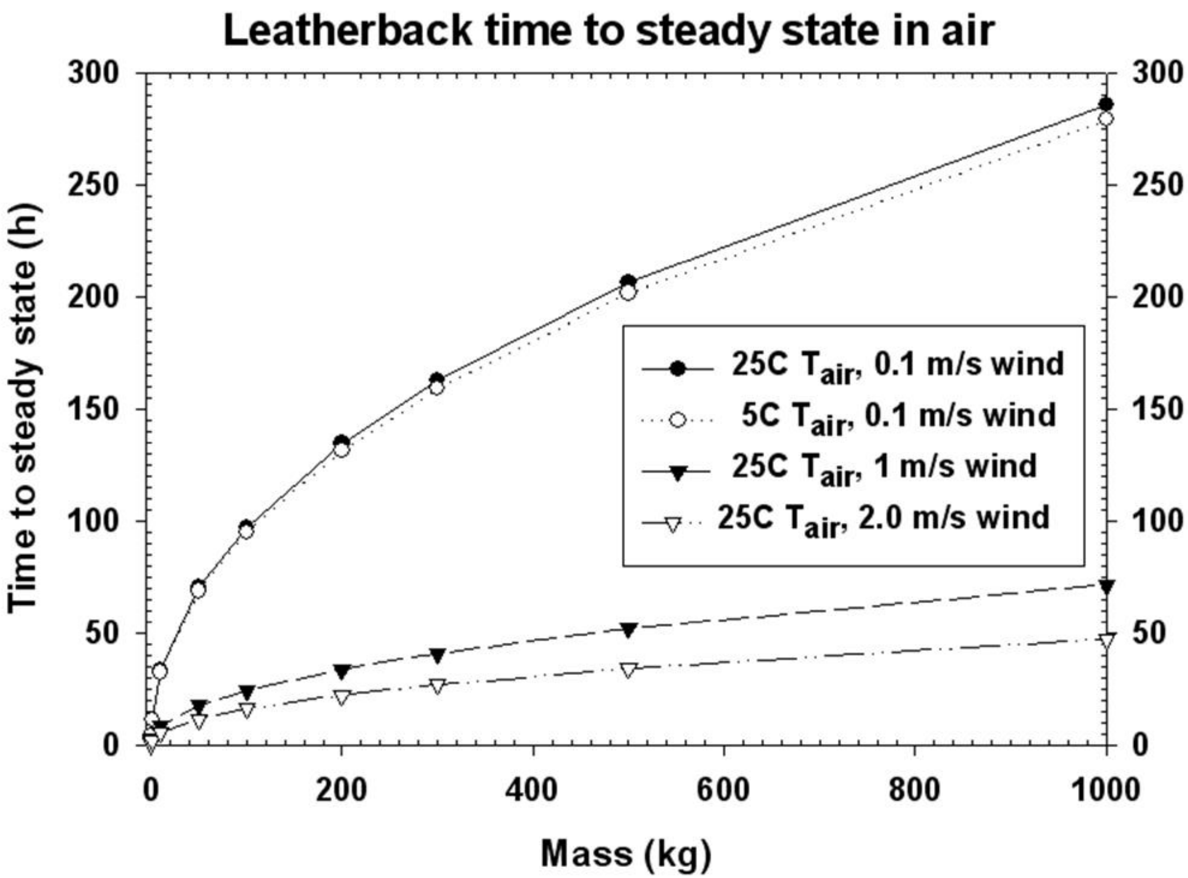


2100

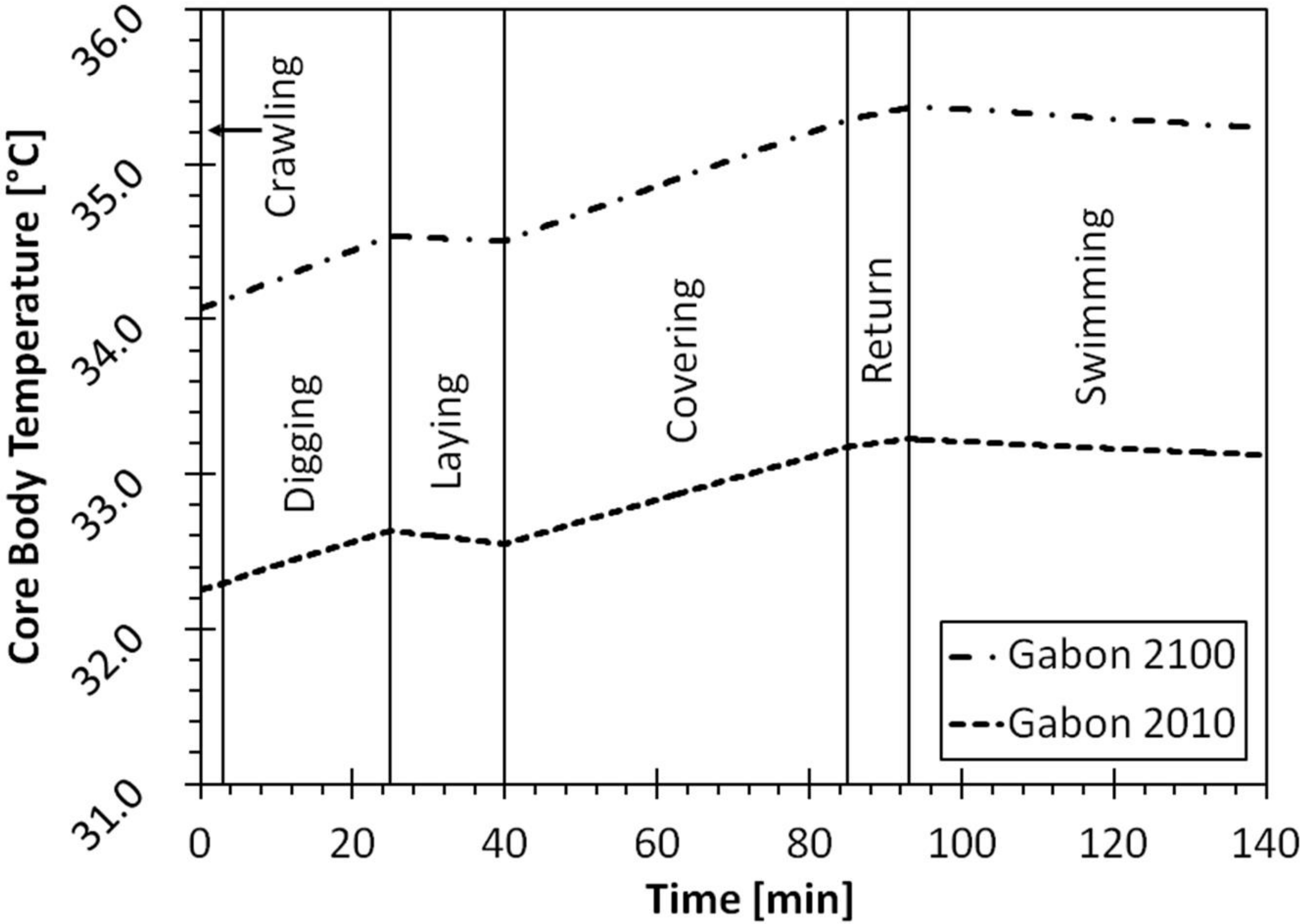
A representation of the four thermal regions (core, insulating layer, air and ground) that comprise the transient thermal model.



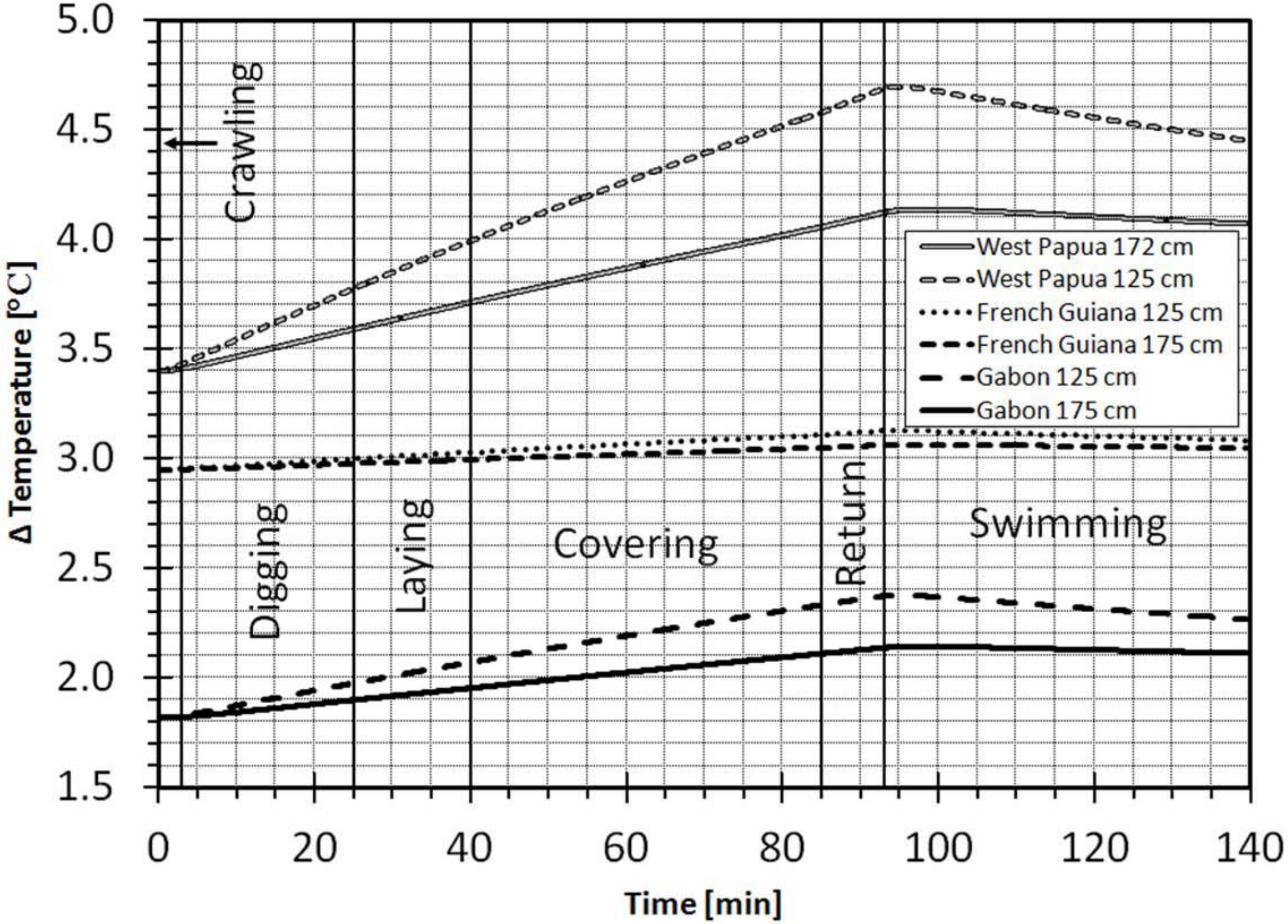
Successful egg laying environmental requirements?



An example, core temperature profile for a 172 cm CCL Gabon leatherback under emission scenario RCP8.5, "business as usual".

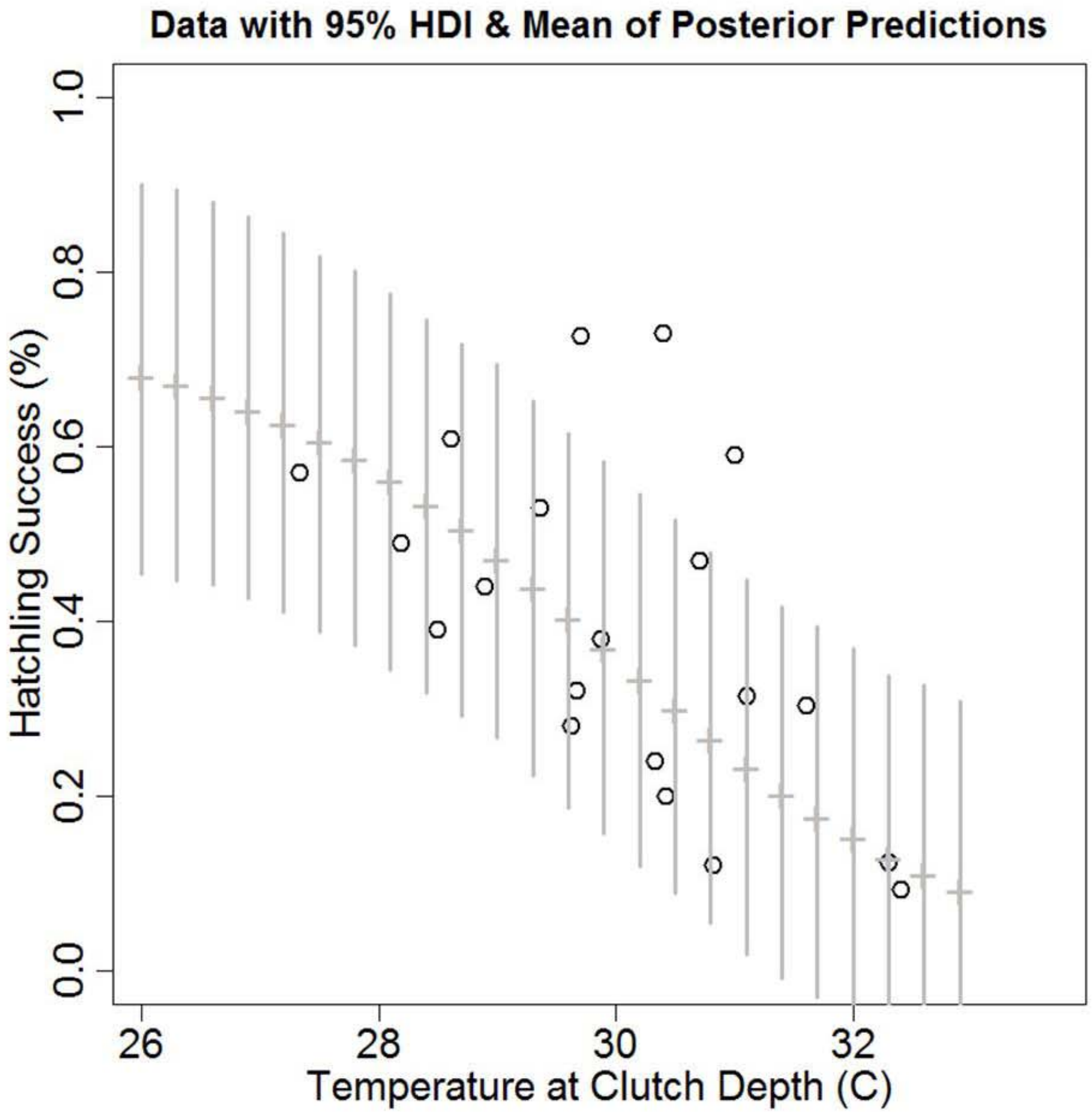


The increase in leatherbacks body temperature during the nesting process between present and emission scenario RCP8.5 for the year 2100.

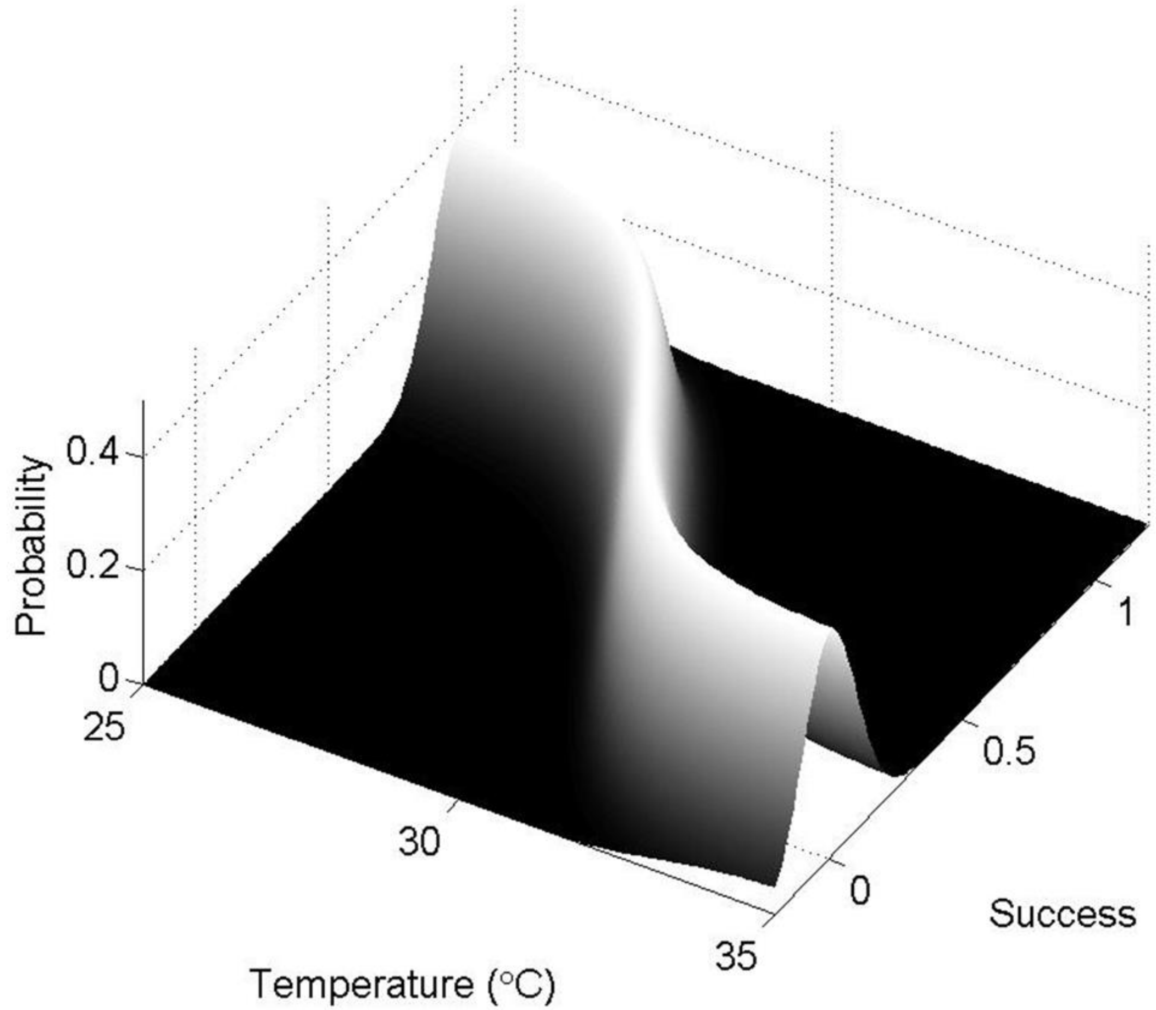


Probability of successful hatching?

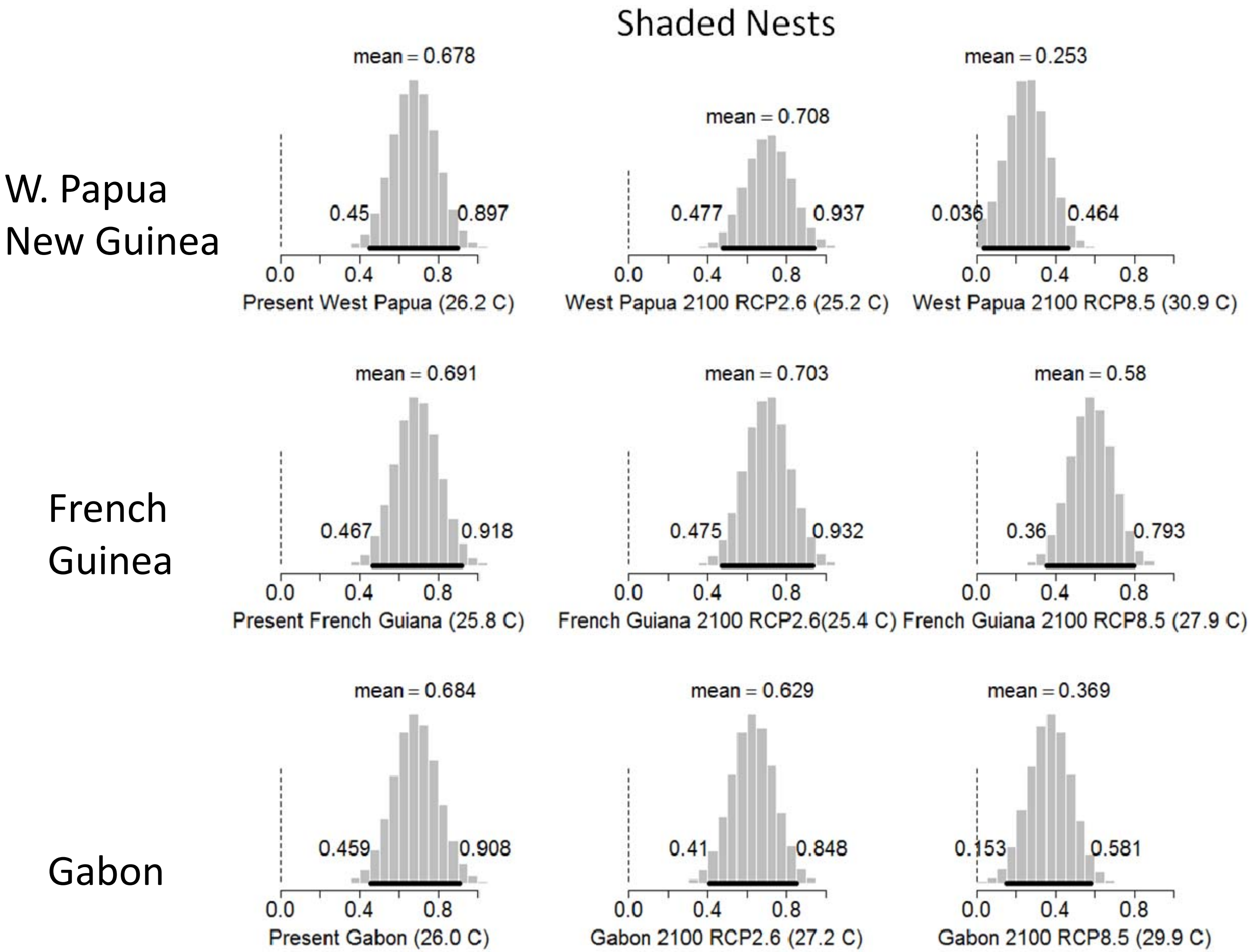
A graph of the raw data from four studies (Tapilatu & Tiwari 2007, Houghton et al. 2007, Santidrián Tomillo et al. 2009, Patino-Martinez et al. 2012) with 95% HDIs overlaid at several temperature values.



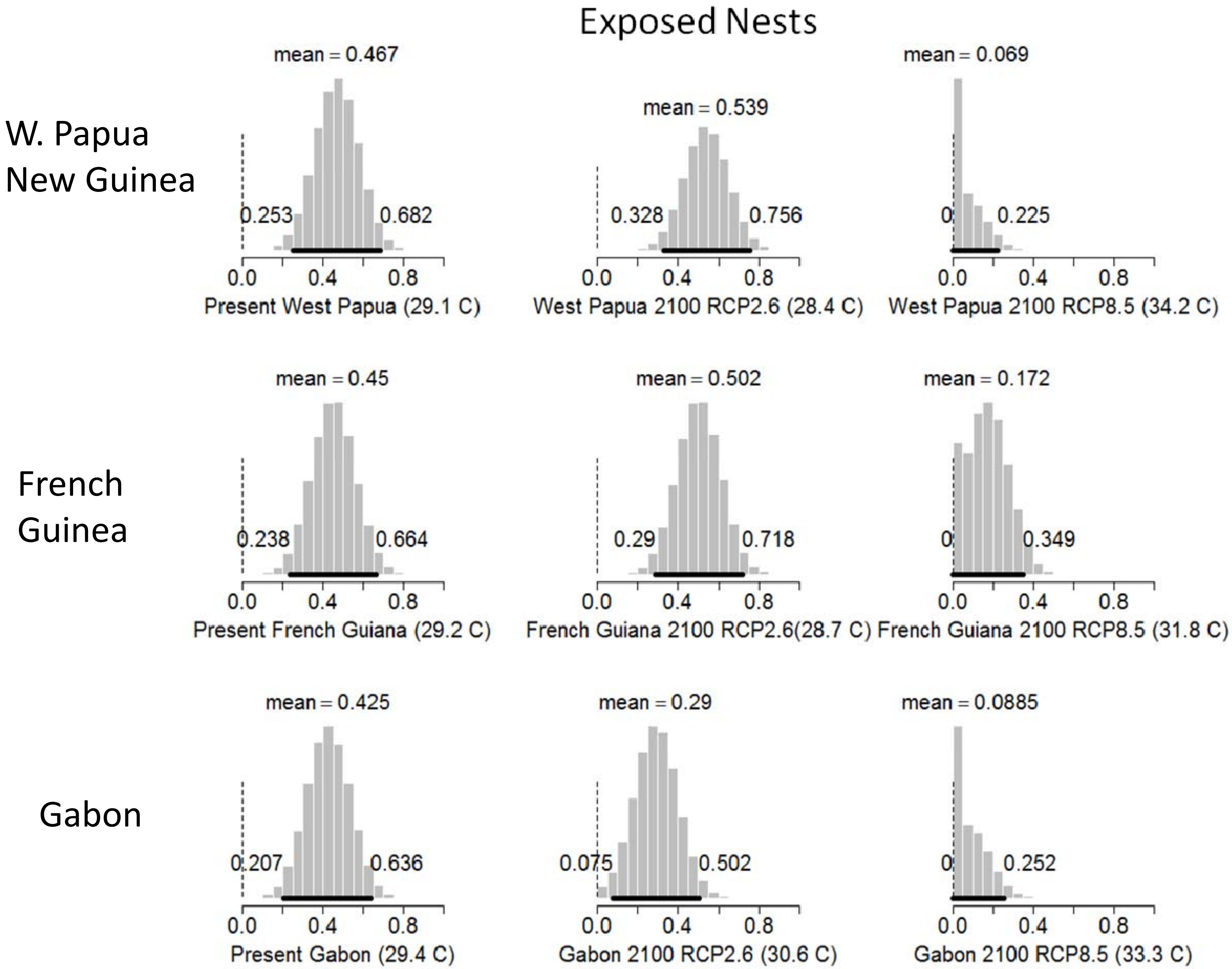
A representation of the likelihood function used in the hatchling success vs. temperature Bayesian regression.



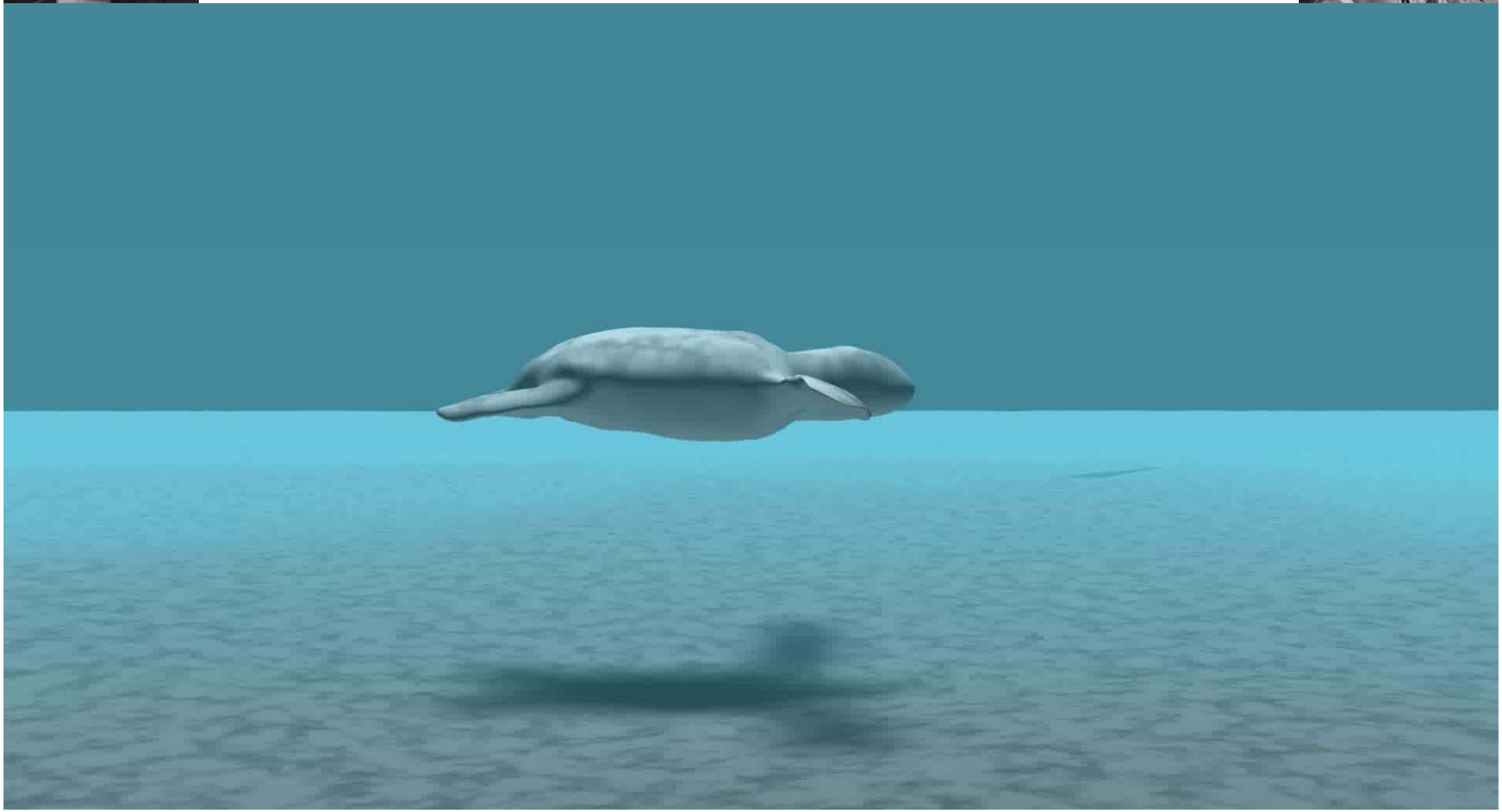
Probability of successful hatching for present, 2100 low CO2, 2100 high CO2).



Probability of successful hatching for present, 2100 low CO2, 2100 high CO2).

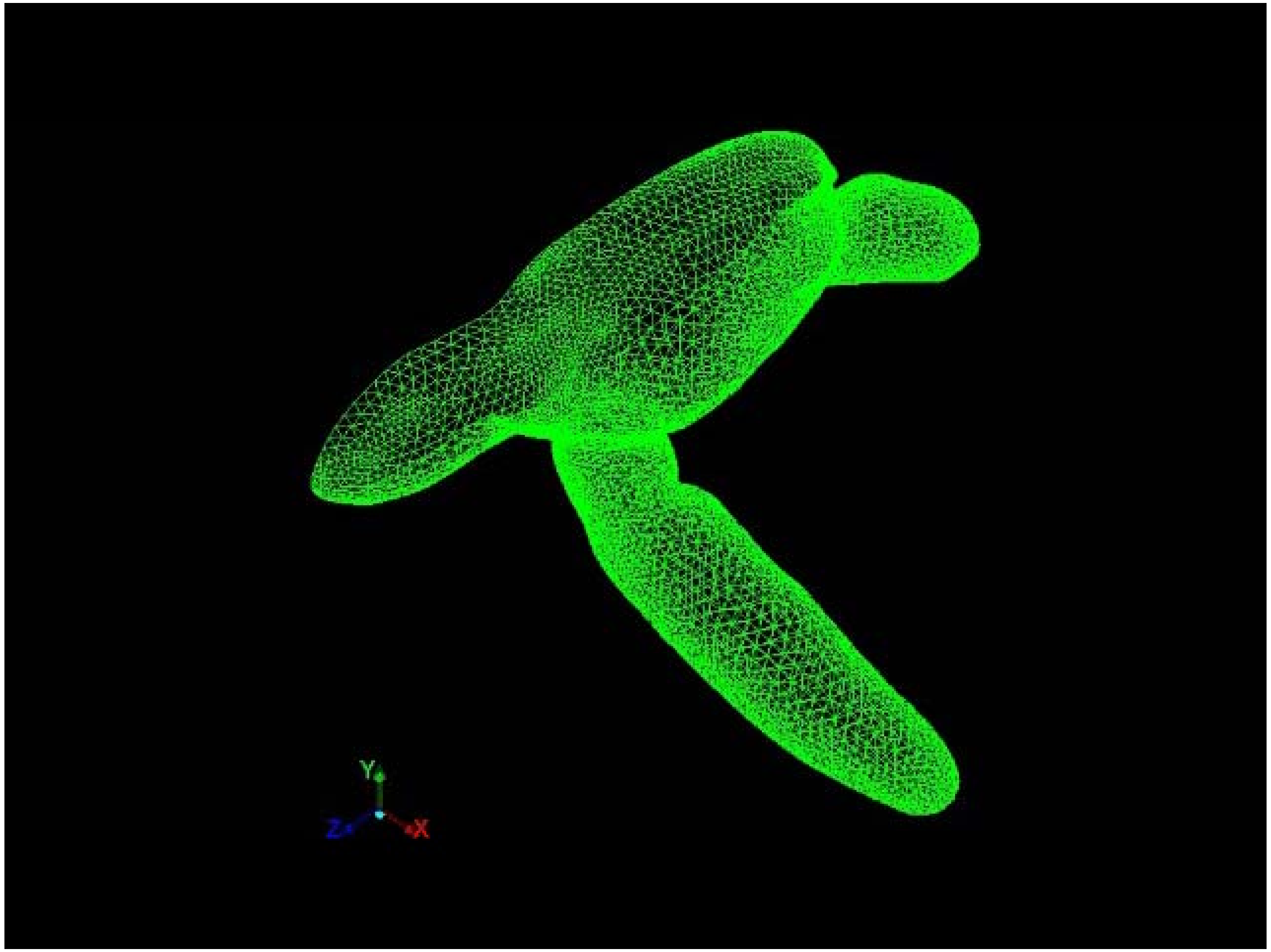


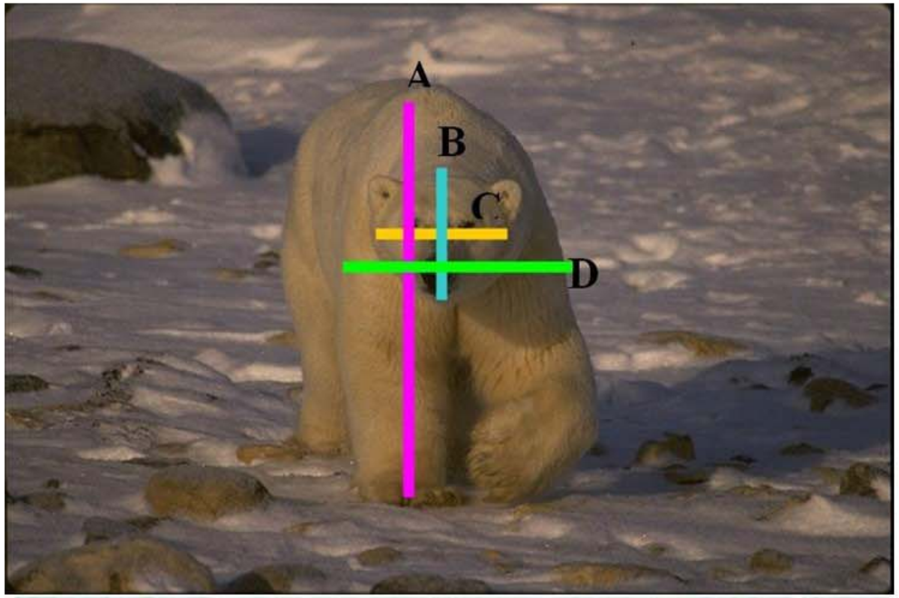
Chad Smith and Steve Hilyard, Art Department, UW Madison



The original time traveler from 170 million years ago

CFD turtle





A
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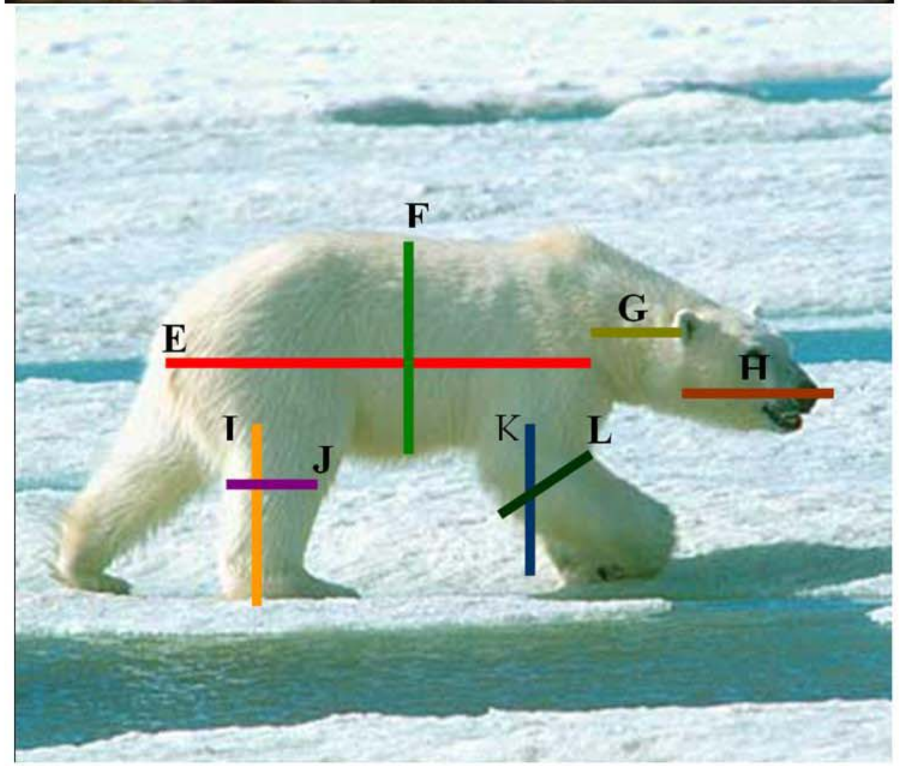
F
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Niche Mapper - Overview - individual focus