The Mechanics of Diving Birds: Effect of Impact Forces as Birds Enter Water

Ravi Kappiyoor and Aschvin Chawan
Dr. Sunghwan Jung

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Final Presentation

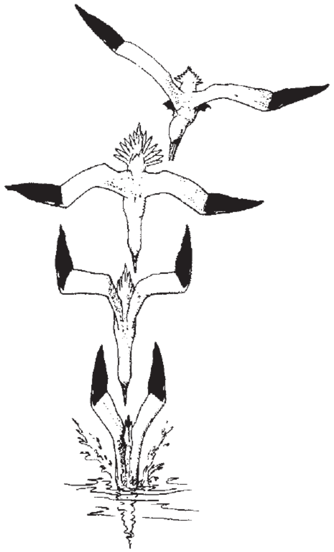
http://ngm.nationalgeographic.com/2012/08/gannets/img/03-diving-off-shetland-coast-670.jpg[1]

Outline

- Animals Analyzed
- Methodology
- Parameter Estimates
- Numerical Simulations
- Results
- Future Work

The Gannet

1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2

http://www.nhm.ac.uk/visit-us/whats-on/temporary-exhibitions/wpy/prevPhoto.do?photo=2711&year=2011&category=2[1]
http://www.youtube.com/watch?v=EwPrXOtBoVg[2]
Lee, Davis N., and Paul E. Reddish. "Plummeting gannets: a paradigm of ecological optics." *Nature* (1981)[3]

Light Mantled Sooty Albatross, Brown Pelican, Double Crested Cormorant

3

1

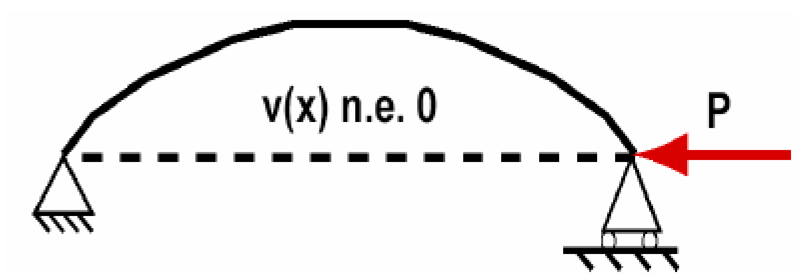
2

http://www.wildimages-phototours.com/tour_images/90501753.jpg[1]
http://www.factzoo.com/sites/all/img/birds/brown-pelican.jpg[2]
http://ontfin.com/Word/wp-content/uploads/2009/04/double_crested_cormorant15.jpg[3]

Methodology

- We plan to model two hydrophobic spheres connected by an elastic polymer beam
- Euler-Bernoulli Beam theory
  - Assume geometric nonlinearity
  - Initially assume elastic

$$\rho A \frac{\partial^2 v}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(EI \frac{\partial^2 v}{\partial x^2} \right) = \frac{P}{L}$$



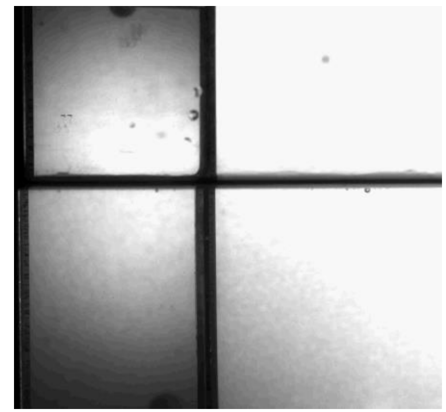
Critical Force

- What is the critical force that will cause buckling of the spine?
- Use steady-state equation

$$\left(EI\frac{\partial^2 v}{\partial x^2}\right) + Pv = 0$$

Critical Force (cont'd)

- Assume slopes at end are 0 due to constraints of the balls (validated by experimental video)



- Solving for critical force gives

$$P_{crit} = \frac{\pi^2 EI}{L^2}$$

Impact Force

- Negligible velocity lost as bird impacts
- Primary force is drag

$$P = \frac{1}{2}\rho C_D V^2$$

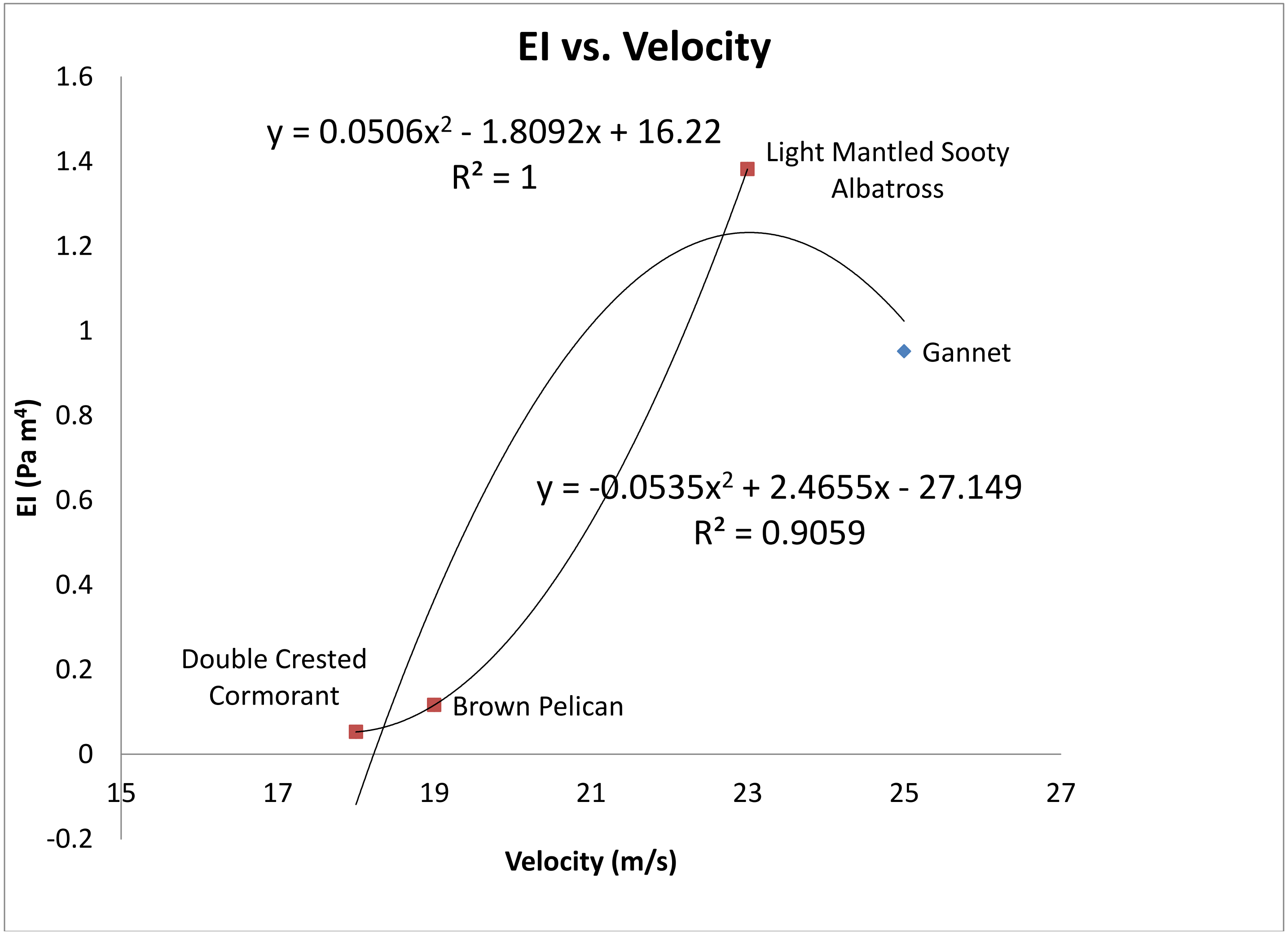
- Solving for EI

$$EI = \frac{\rho L^2}{2\pi^2} V^2$$

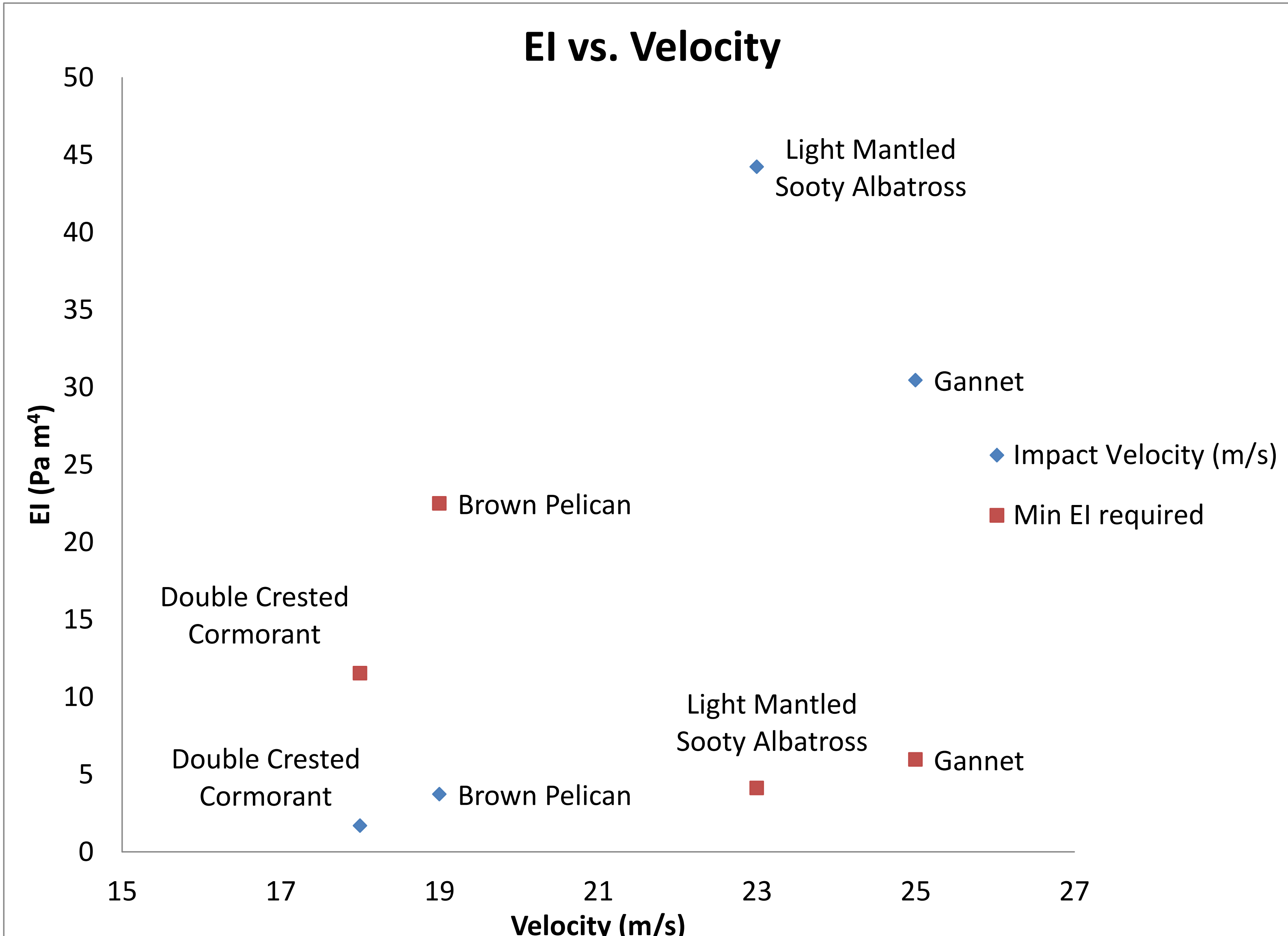
Assumptions & Data

	Light Mantled Albatross	Brown Pelican	Northern Gannet	Double Crested Cormorant
Velocity (m/s)	2.30E+01	1.90E+01	2.50E+01	1.80E+01
Neck Thickness (m)	1.34E-01	7.22E-02	1.22E-01	5.93E-02
Spine Radius (m)	3.35E-02	1.80E-02	3.05E-02	1.48E-02
Dive Height (m)	3.10E+01	1.80E+01	3.00E+01	1.70E+01
Weight (g)	3.10E+03	3.70E+03	2.90E+03	1.90E+03
Mass of Spine (g)	1.55E+00	1.85E+00	1.45E+00	9.50E-01
Elastic Modulus (Pa)	2.236E+07	2.236E+07	2.236E+07	2.236E+07
Moment of Inertia (m^4)	1.98E-06	1.66E-07	1.36E-06	7.56E-08
EI	4.42E+01	3.72E+00	3.05E+01	1.69E+00
Height (m)	3.50E-01	6.80E-01	3.80E-01	5.10E-01
Density (kg-m^-3)	1.26E+00	2.66E+00	1.30E+00	2.70E+00
Min EI	4.12E+00	2.25E+01	5.96E+00	1.15E+01

Comparison of EI to V



Comparison of EI to Min EI



Numerical Simulations

- Begin by modeling dumb-bell system

$$\rho A \frac{\partial^2 v}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(EI \frac{\partial^2 v}{\partial x^2} \right) = \frac{P}{L}$$

- Non-dimensionalize

$$\frac{\partial^2 \overline{v}}{\partial \overline{t}^{\,2}} + \frac{\partial^4 \overline{v}}{\partial \overline{x}^{\,4}} = \frac{\overline{P}}{\overline{L}}$$

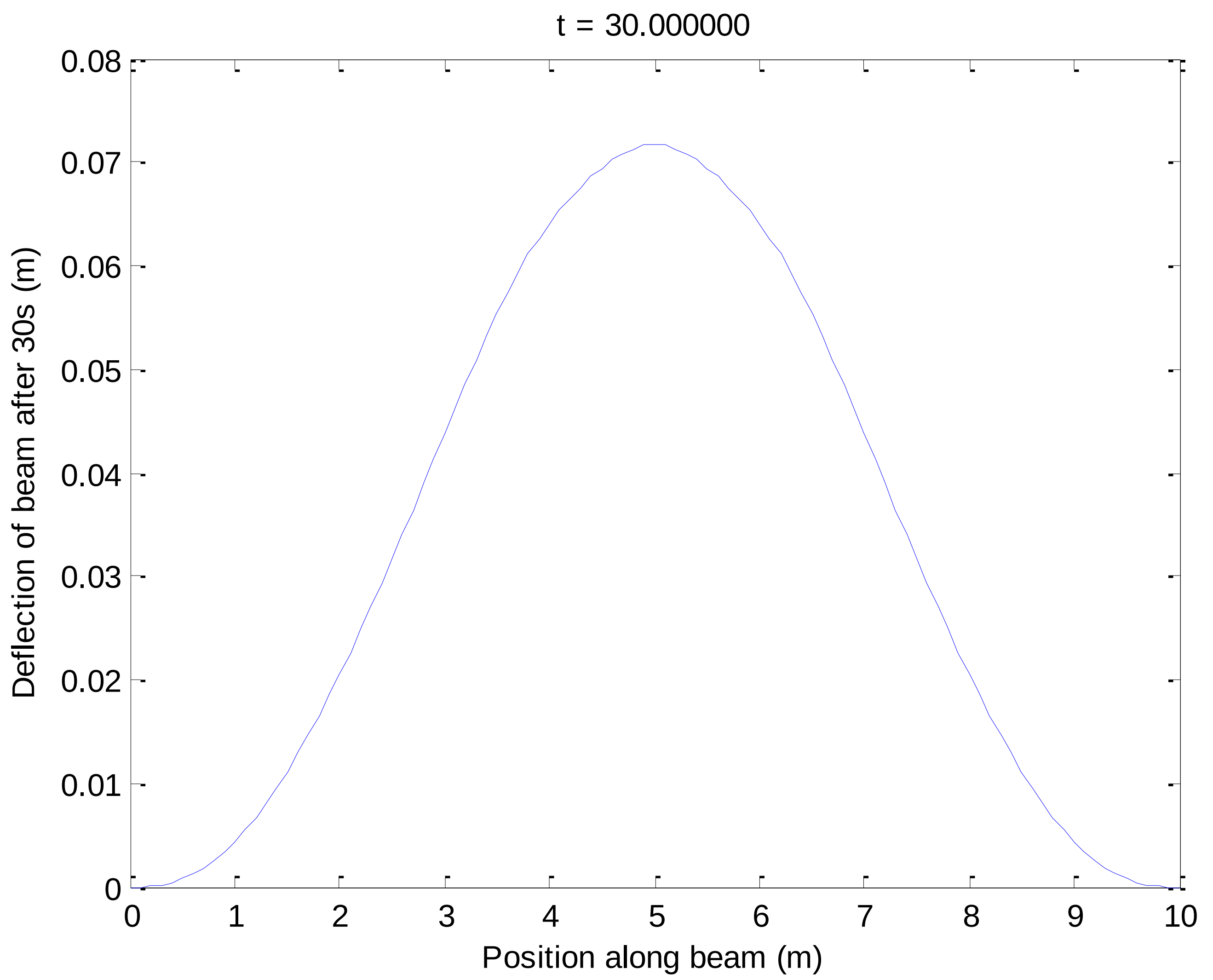
Numerical Simulations (cont'd)

- Finite Element Analysis

$$\left(\ddot{d}_i \int_0^L \psi_i \psi_j \mathrm{d}x + d_i \int_0^L \frac{\mathrm{d}^2\psi_i}{\mathrm{d}x^2} \frac{\mathrm{d}^2\psi_j}{\mathrm{d}x^2} \mathrm{d}x - \frac{P}{L} \int_0^L \psi_j \mathrm{d}x \right) e_j = 0$$

$$M_{ij} \ddot{d}_j + K_{ij} d_j = F_i$$

Results



t = 30.000000
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Deflection of beam after 30s (m)
0
1
2
3
4
5
6
7
8
9
10
Position along beam (m)

Future Work

- Better mechanical properties of birds
- Continue work on numerical model
  - Finish matching with experiment
  - Refine model to include force absorption by spheres, different mass spheres, shape of spheres, angle of impact, etc.