# Trimmed bird flight : simulation and performance quantification

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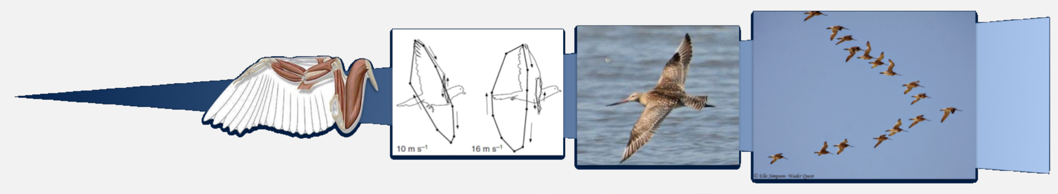


RevealFlight

## Motivation

- Birds exhibit **impressive endurance and energy efficiency**
- How they reach such performance, however, is **poorly understood**
- **Reproduction of these performance** is the key to fully grasp what makes bird flight so efficient
- A **bottom-up, reverse engineering approach** to retrieve flying gaits through optimization rather than plain mimicry

## Methods

### A 3D fluid solver

- **Lifting lines**
- **Aerodynamic forces** on the wing
- Evolution of the bird's **wake**

### A multibody system

- Based on birds' **anatomy**
- Anatomic features (bones, …)
- Modeling the **plumage** using a few "master feathers"

## The fluid solver

- 3D **Vortex Particle-Mesh** method solving the Navier-Stokes equations in their vorticity-velocity formulation
- The wing is modelled as a **lifting line** producing vorticity in the flow
- **Requires the description and kinematics** of the lifting line
- The aerodynamic forces are computed **on points of the line** using polar data

## The multibody solver

- Integrates the motion equations of a multibody system modeling the bird
- The wing is modelled using bones and feathers
- Requires the **aerodynamic forces on the lifting bodies of the wing**
- Prescribed kinematics or joint torques to actuate the bird as input
- Outputs the **kinematics of the solid bodies**

## Coupling the models

Forces on the points of the lifting line

Forces on the anatomical features (feathers and propatagium)

*The bird we used as a reference for the model is the Northern Bald Ibis

**3D Fluid solver**

**Bird wing model***

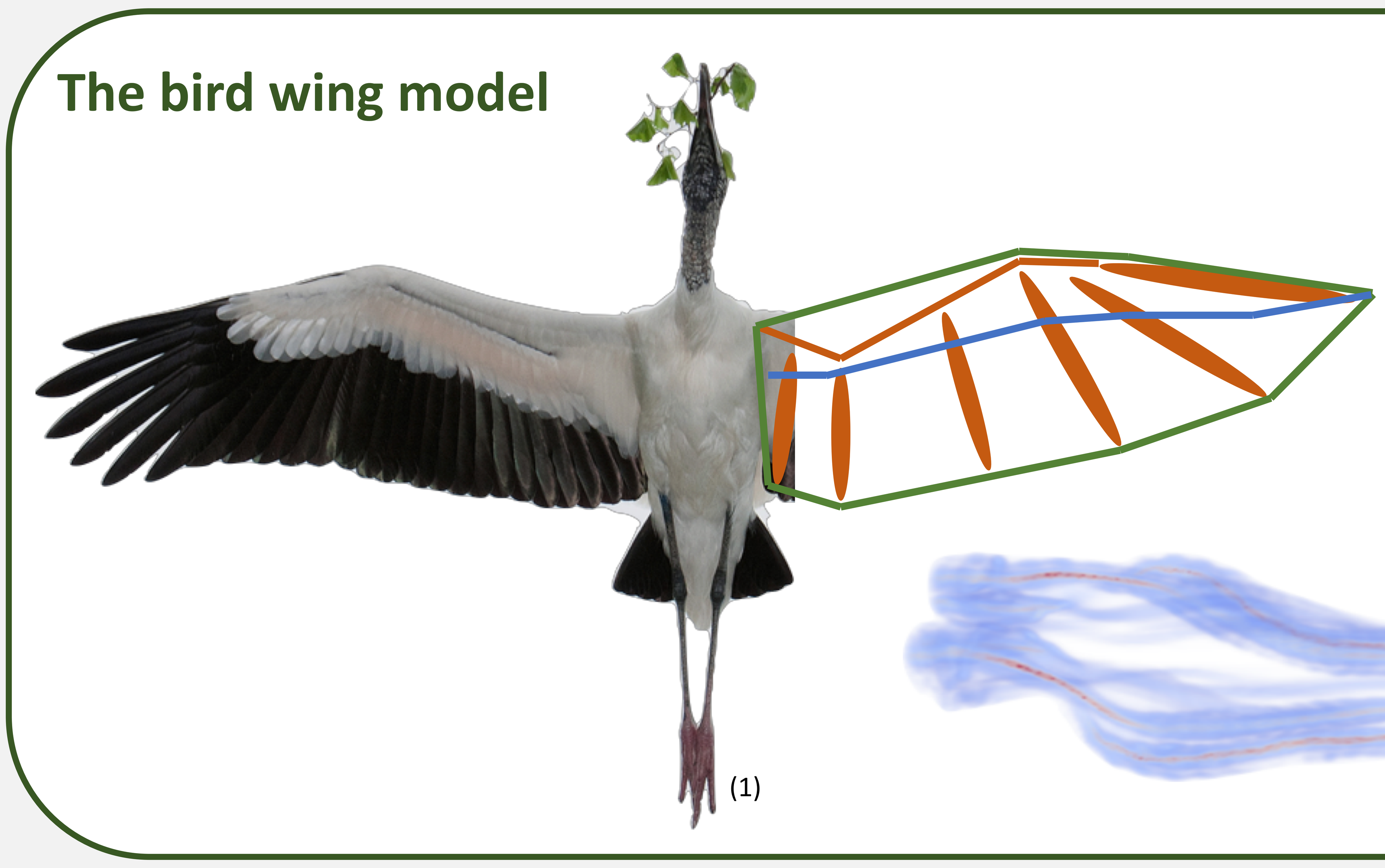
**Multibody system**

Characteristics and kinematics of the lifting line

Kinematics of the skeleton and feathers

Joint/muscle torques/forces to actuate the system

## The bird wing model



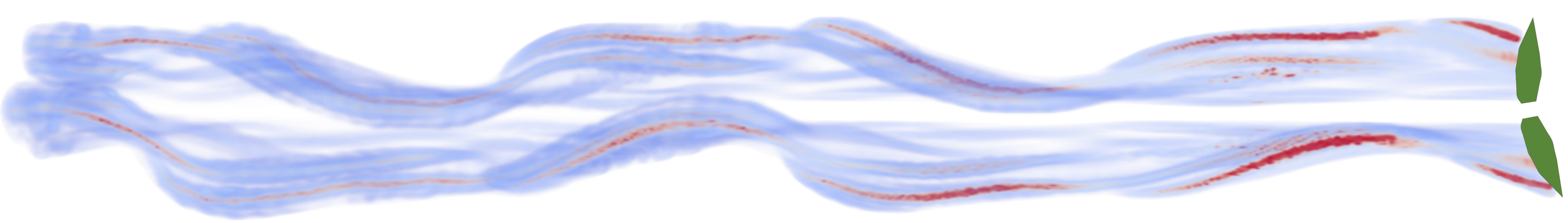
(1)

### From multibody to fluid

- Extract the **leading and trailing edges of the wing** (resp. the front of the **arm** and the tip of the **feathers**)
- Compute the **lifting line** position (at the quarter of the chord), discretize and characterize it

### From fluid to multibody

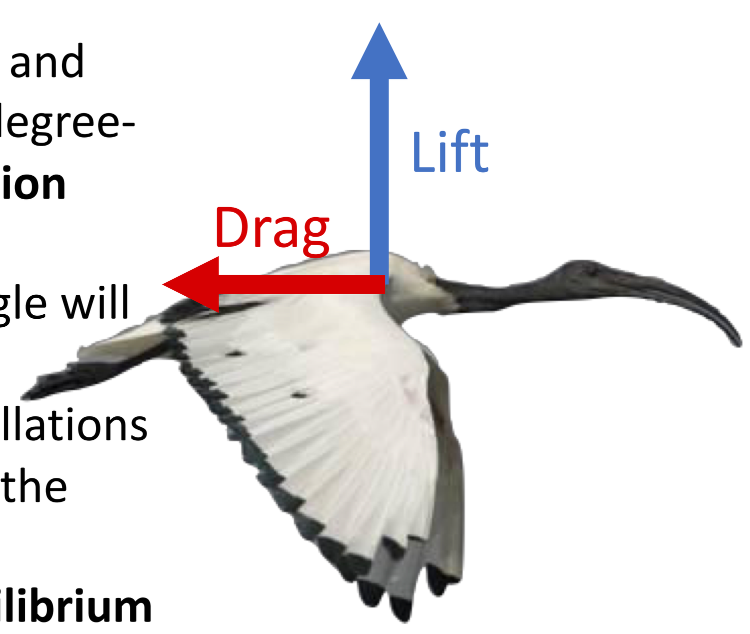
- For each point of the lifting line, find the closest feather
- Distribute the forces of the lifting line points on the feathers accordingly
- Add torques due to the distance of the force application point

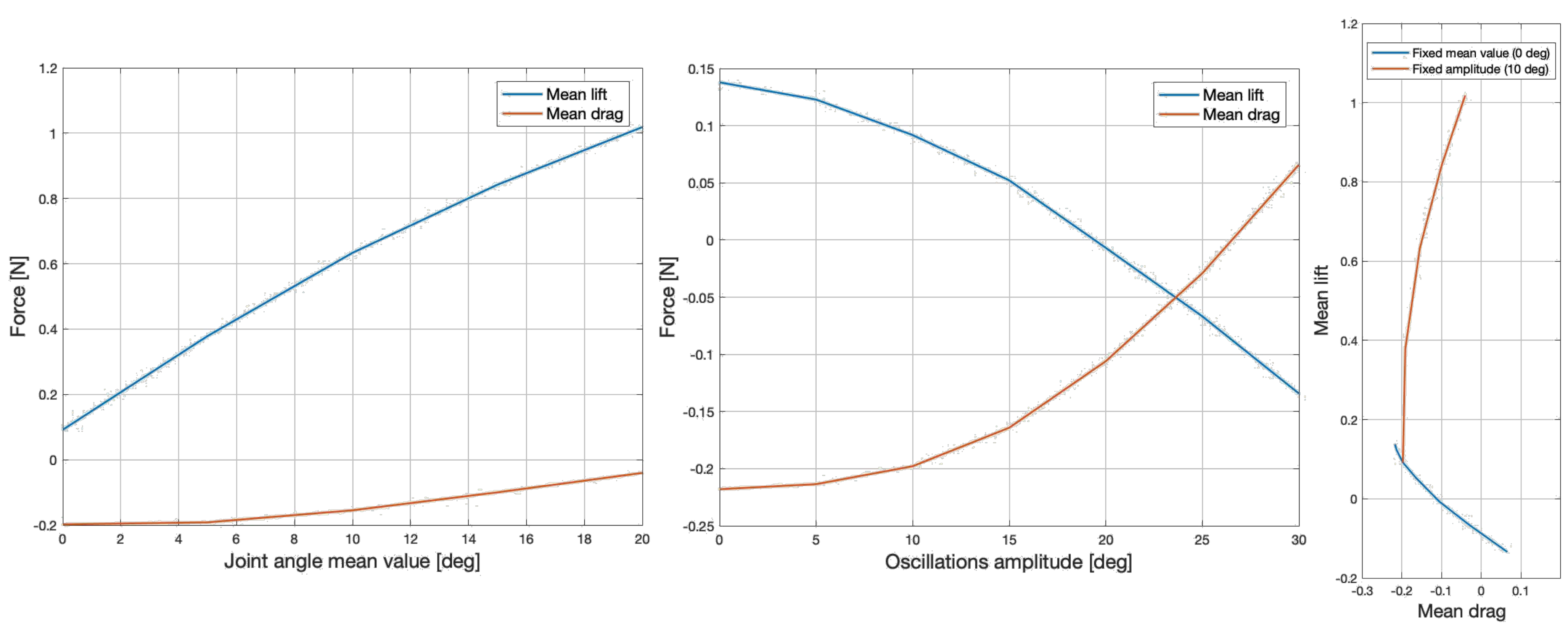


Vorticity magnitude in the wake of a flying bird

## Towards controlling the bird

- For a given wingbeat amplitude and frequency, the most impactful degree-of-freedom is the **forearm rotation along the wing axis**
- The **mean value** of this joint angle will primarily affect the **lift**
- The **amplitude** of the angle oscillations at this joint will primarily affect the **thrust**
- It is possible to reach **force equilibrium** by tuning these two parameters




## Conclusion and perspectives

- The resulting framework allows a **comprehensive simulation** of bird flight, coupling phenomena going from the **neural motion generation to the aerodynamics**
- **Force equilibrium** clearly achievable, as well as **closed loop stability**
- The gait can be studied and optimized to achieve **maximum energy efficiency**
- **Muscle models** can readily be implemented

## References

(1) http://www.birdsasart-blog.com/2014/05/28/birds-as-art-2nd-international-bird-photography-competition-digital-flight-winners-the-readership-vote/

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