A Linearized Model for an Ornithopter in Gliding Flight: Experiments and Simulations

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Summary

1. Motivation.
2. Theoretical model.
3. Simulator.
4. Experimental setup.
5. Results and discussion.
6. Future work.
1. Motivation

- Simple but effective analytical model for a flapping-wing UAV in longitudinal flight.
- Experimental validation of the gliding flight with a launch platform.
- Realistic simulator with embedded model equations for gliding and flapping configurations.
2. Theoretical model

- Simple linearized model for gliding and flapping based on linearized potential theory.

- Previous work:
  - R. Fernandez-Feria et al. (2016 and 2017)[1][2]
  - A. Martín-Alcántara et al. (2019).

- Suitable for high Reynolds numbers, low flapping amplitudes and moderate frequencies.

- Non-dimensional model: Easily extendable to other designs.

[1] https://doi.org/10.1017/jfm.2017.500
[2] https://doi.org/10.1103/PhysRevFluids.1.084502
2. Theoretical model: Parameters and equations

- Newton-Euler equations in a non-inertial reference frame.
- Non-dimensional parameters.
- Aerodynamics forces are modeled following Fernandez-Feria (2016, 2017)
  - Induced and parasitic drag are considered. The latter through Lighthill's number (Li)
3. Simulator: Framework

- Integrated in the UE4 Airsim framework.
- Fast calculation of dynamic equations: Gliding, flapping and transitions.
- Modular framework:
  - Realistic render engine.
  - Sensor model provides camera, barometer, IMU, GPS, Magnetometer, distance sensor and lidar.
  - Environment model.
  - Physics engine.
3. Simulator: Performance

- Stable visualization.
- Robust collision detection at physics engine refresh rate.
- Communication API in C++ and python:
  - Control.
  - Image streaming.

| Physics engine | Render engine |
|----------------|---------------|
| ~300 Hz        | ~60 Hz        |
4. Experimental Setup: Platform

- The tests have required a careful setup
- Fuselage made of carbon fiber.
- Wings and tail made of ripstop nylon.
- Actuation mechanism:
  - Wings: Alternative vertical motion with a machined aluminum mechanism.
  - Tail: Roll servomotor and Pitch servomotor mechanism.
4. Experimental Setup: Hardware specifications

- Boards: Raspberry Pi Zero and Arduino Micro.
- Radio controller.
- IMU: POLOLU AltIMU-10 V5:
  - Accelerometer ±2g.
  - Gyroscope ±2000°/s
  - 204Hz
- Powered by a 2S battery with 500 mAh.
4. Experimental Setup: Launcher platform

- Assembled to control flight initial conditions.
- Guarantees reliability and repetitiveness.
- Launcher, sliding and propulsion system.
4. Experimental Setup: Scenario

- The scenario chosen:
  - Launch height: 18m
  - Temperature: 36°C
  - Wind velocity: 20km/h

- Pitch and pitch rate:
  - AHRS

- Longitudinal velocity:
  - Three cameras tracking the platform.
  - SFM algorithm with bundle adjustment to recover 3D position.
5. Results and discussion: Experiments

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5. Results and discussion: Experiments

- Most representative magnitudes:
  - Altitude
  - Longitudinal speed
  - Pitch
  - Gliding angle

- Computed with a Runge-Kutta method of fourth order.
- The results demonstrates a suitable inertial dominance across all experiments.
- Reynolds number similar to that of medium-sized birds such as gulls and vultures.

\[ Re = \frac{U_c c}{\nu} \sim \mathcal{O}(10^5) \]
5. Results and discussion: Comparison

- Maximum deviation of experimental measurements.
- Altitude and speed match.
- Noisy pitch angle: EKF + low-pass filter + AHRS.
- Gliding angle match better in steady-state.
- Gust disturbances.
- Trajectory not fully rectilinear.
6. Conclusions and future work

- Simple model to understand the aerodynamic behavior
- Crucial launcher platform
- Novel simulator incorporating model equations

- Experimental validation of flapping-wing flight episodes
- Multiple ornithopters cooperation
- High autonomy. Surveillance and rescue task
Thanks for your attention