• Acknowledgements to

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• Project based in the paper: “Nonlinear time-periodic models of the longitudinal flight dynamics of the desert Schistocerca gregaria” by Graham K Taylor and Rafal Zbikowski
• Introduction

• Approaches to study aerodynamics:
  – Flow visualization
  – Computational fluids dynamics
  – Aircraft stability
• How to model flight of insects

- Approach used for helicopters or airplanes can be a time invariant system:
  \[ \dot{x} = f(x) \]

- A better representation by time variant systems:
  \[ \dot{x} = f(x, t) \]

- Since Taylor and Thomas (2003) suggest a linearized framework, but linearized fails to explain stability.

- It is based in Newton-Euler rigid body equations of motion
• Issues on flight of insects
  ❑ It is different to the approach used for helicopters or airplanes
  ❑ How to model instantaneous force production from wings
  ❑ Information from experiments:
    ❑ - Measure forces and moments from wings
    ❑ - Obtain weight and moment of inertia
What else to know from locusts

- All locusts are significantly different in sizes
- A typical locust flies in cruise speed of 4 m/s
- The span is around 0.1m
- It is flapping at 20Hz
- As any insect has 4 wings
  - 2 forewings which sweeps 110°
  - 2 hindwings which sweeps 70°
- A locust use its antennae and hair on the head to sense the air speed
- Center of mass is fixed (because 4% of the total weight is in the wings)
- Body is symmetric in the longitudinal axis
What to know to model a flight of a locust

- Newton-Euler Equations

\[ \dot{u} = -wq + \frac{X}{m} - g \sin \theta \]
\[ \dot{w} = uq + \frac{Z}{m} + g \cos \theta \]
\[ \dot{q} = \frac{M}{I_{yy}} \]
\[ \dot{\theta} = q \]

- From these equations implies that we have:
  - Center of gravity is fixed
  - Body is symmetric in the longitudinal axis
  - Four state variables
  - Constant mass, moment of inertia and gravity
What is needed from experiments

- Three type of locusts
- It is used a wind tunnel
- Data collected under different angles (from 0 to 14 degrees)
- Data collected under different velocities of the wind tunnel (from 2 to 5.5 m/s)
- It was taking between 2-3h for collecting data for each locust
We also need to know:

- Incomplete data in locust that failed in the experiment were discarded.
- A systematic variation in wing beat frequency will alter the dynamics.
- Data from experiments can be well fitted in Fourier series using until the eight harmonics order.
Plot reproduced for the X force for one wing beat period at different angles of the insect.
• Plot reproduced for X force
• For one wing beat period
• At different values of U velocity.
• Z force for one wing beat period
• M moment for one wing beat period
We also need to know:

- Fourier series equation:

  \[ P(t) = \sum_{n=0}^{h} (a_n \cos n\omega t + b_n \sin n\omega t) \]

- From the Fourier series we can have two types of models:
  - Nonlinear time invariant (NLTI) model just considering the zero harmonics
  - Nonlinear time periodic model (NLTP) considering until the eight harmonics
• Equations used to represent forces and moment

\[
X(\alpha, U, t) = \sum_{n=0}^{8} (a_{1,n} \cos n\omega t + b_{1,n} \sin n\omega t) + (\alpha - \alpha_{ref}) \sum_{n=0}^{8} (a_{2,n} \cos n\omega t + b_{2,n} \sin n\omega t) + (U - U_{ref}) \sum_{n=0}^{8} (a_{3,n} \cos n\omega t + b_{3,n} \sin n\omega t)
\]

\[
Z(\alpha, U, t) = \sum_{n=0}^{8} (a_{1,n} \cos n\omega t + b_{1,n} \sin n\omega t) + (\alpha - \alpha_{ref}) \sum_{n=0}^{8} (a_{2,n} \cos n\omega t + b_{2,n} \sin n\omega t) + (U - U_{ref}) \sum_{n=0}^{8} (a_{3,n} \cos n\omega t + b_{3,n} \sin n\omega t)
\]

\[
M(\alpha, U, t) = \sum_{n=0}^{8} (a_{1,n} \cos n\omega t + b_{1,n} \sin n\omega t) + (\alpha - \alpha_{ref}) \sum_{n=0}^{8} (a_{2,n} \cos n\omega t + b_{2,n} \sin n\omega t) + (U - U_{ref}) \sum_{n=0}^{8} (a_{3,n} \cos n\omega t + b_{3,n} \sin n\omega t)
\]

• In summary, previous equations follows:

\[
P(\alpha, U, t) = P_{ref}(t) + P_{\alpha}(t)(\alpha - \alpha_{ref}) + P_{U}(t)(U - U_{ref})
\]

• Where P involves a vector with the forces:

\[
P = [X, Z, M]
\]
• From the original Newton-Euler equations:

\[
\begin{align*}
\dot{u} &= -wq + \frac{X}{m} - g \sin \theta \\
\dot{w} &= uq + \frac{Z}{m} + g \cos \theta \\
\dot{q} &= \frac{M}{I_{yy}} \\
\dot{\theta} &= q
\end{align*}
\]

• It’s going to look as:

\[
\begin{align*}
\dot{u} &= -wq + \frac{X_{\text{ref}}(t)}{m} + \frac{X_{\alpha}(t)}{m} \left( \tan^{-1} \frac{w}{u} - \alpha_{\text{ref}} \right) + \frac{X_{U}(t)}{m} \left( \sqrt{u^2 + w^2} - U_{\text{ref}} \right) - g \sin \theta \\
\dot{w} &= uq + \frac{Z_{\text{ref}}(t)}{m} + \frac{Z_{\alpha}(t)}{m} \left( \tan^{-1} \frac{w}{u} - \alpha_{\text{ref}} \right) + \frac{Z_{U}(t)}{m} \left( \sqrt{u^2 + w^2} - U_{\text{ref}} \right) + g \cos \theta \\
\dot{q} &= \frac{M_{\text{ref}}(t)}{I_{yy}} + \frac{M_{\alpha}(t)}{I_{yy}} \left( \tan^{-1} \frac{w}{u} - \alpha_{\text{ref}} \right) + \frac{M_{U}(t)}{I_{yy}} \left( \sqrt{u^2 + w^2} - U_{\text{ref}} \right) \\
\dot{\theta} &= q
\end{align*}
\]
Response to minimum changes in the horizontal velocity for the Nonlinear time invariant model (NLTI)
Response to minimum changes in the initial value of time for the Nonlinear time periodic (NLTP) model.
Response to minimum changes in the initial value of time for the Nonlinear time periodic (NLTP) model.
How the value $\theta$ is changing with respect to the other variables ($u$, $w$ and $q$):
DISCUSSION AND DRAWBACKS

- Unstable model because
  - Experimental data may be not representative of a free flight
  - Data may be altered because of instruments used
  - Center of mass is constant and the moment of inertia is time invariant
  - There are still some limitations in the data collection
FUTURE WORK

- Show results for the other two type of locust
- Obtain plot for longer time of simulation
- Include any possible technique to control the flight (Variable coefficients in the Fourier Series)
QUESTIONS?