Flight Dynamic Simulation of a Multibody Configuration using an Integrated Euler Solver

By
M. Harshavardhan, Om Prakash, N. Ananthkrishnan
Dept. of Aerospace Engg., IIT Bombay

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Introduction

- Wing-payload systems
- Integrate the CFD solver with the Flight dynamics solver -
  → Active Integration
  → Passive Integration
- Aerodynamic analysis of a 3D aerodynamic body using Euler simulations
- Flight dynamics - Detailed derivation of 4-DOF longitudinal flight dynamic equations
- Flight dynamic simulation - Detailed time histories of the various flight parameters
Flight Dynamics

- 9-DOF model used for describing flight dynamics of Wing-Payload system
- Two-body system consisting of wing and payload (each with 3 rot. DOF) and a connection pt. C (having 3 trans. DOF)
- Apparent mass effects
- Vertical offset between wing AC and CG of the system
- Rigging angle, Mass of payload and Length of link $R_w$ are important design parameters
Assumptions

- Present study adopts a 4-DOF model obtained from the 9-DOF model presented by Slegers & Costello.
- Two rigid masses (i.e. wing mass $m_w$ and payload mass $m_p$)
- Rigid massless links $R_w$ and $R_p$ connect wing and payload to joint C respectively.
- Wing and payload are free to rotate about the joint C but are constrained by the internal joint force.
- Wing mass centre is assumed to coincide with the wing mid-baseline point.
- Earth is considered to be flat and is taken as the inertial frame of reference.
Modeling Approach

- Three body-fixed Cartesian co-ordinate axes -
  - Wing body-fixed axis system
  - Payload body-fixed axis system
  - Joint C body-fixed axis system

- Longitudinal dynamics of the system are characterized by $u_c, w_c, \theta_w, \theta_p, q_w, q_p, \alpha_w, \mu$ and $\gamma$.

- 4-DOF model of wing-payload system is formed by deriving dynamic equations of -
  - Wing Submodel
  - Payload Submodel

Velocities and forces at joint C are assumed to be common.
Wing Submodel

• **Forces acting on the wing submodel** -
  - Gravitational Force
  - Aerodynamic Force
  - Apparent Fluid Force
  - Internal Joint Force

• **Moments acting on the wing submodel** -
  - Aerodynamic Moment
  - Joint Force Moment
  - Apparent Fluid Force Moment

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Payload Submodel

- Forces acting on the payload submodel -
  - Gravitational Force
  - Aerodynamic Force
  - Internal Joint Force

- Moments acting on the Payload submodel -
  - Joint Force Moment

- Drag and gravity forces provide zero external moment.
4-DOF Longitudinal Model of Wing Payload System – Matrix Notation

\[ M\dot{x} = B \]

which can be transformed into

\[ \dot{x} = M^{-1}B \]

equivalent to a dynamical system

\[ \dot{x} = f(x, \mu) \]
Simulation

- CFD Simulation – The Euler solver used in the present study is a Langley Euler Code (v1.0) which -
  - Solves the 3D Euler equations on arbitrary multiblock grids.
  - It uses a central difference type finite volume approach along with the Jameson-Schmidt-Turkel (JST) scheme of artificial dissipation.
  - Time integration is performed using multi-stage Runge-Kutta schemes.
  - Implicit residual smoothing and local time stepping are employed as acceleration devices
  - Euler Solver provides us with Lift and Moment coefficients alone.

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Simulation Contd.

- Flight Dynamic Simulation – Longitudinal 4-DOF equations of the wing-payload system have been coded in MATLAB.

- Passive Integration –
  - An interactive UNIX Shell script has been written as a part of the present study.
  - Automates the complete simulation process
  - It suffices to run the Euler simulations for two different angles of attack and interpolate for the rest of the region.
ONERA M6 Wing

- Span (b) 2.3926m
- Mean Aerodynamic Chord (c) 0.64607m
- Aspect Ratio (AR) 3.8
- Taper Ratio 0.562
- Leading-edge Sweep 30.0 deg
- Trailing-edge Sweep 15.8 deg
- Sweep Angle (at quarter chord) 26.7 deg
- Mass of wing 4 kg
- Length of Link \( R_w \) 4.78 m
- Planform Area 1.5064 \( m^2 \)
- Thickness (t) 0.1 c
- Moment of Inertia of Wing \( (I_w) \) 0.1055 kgm^2
Geometric Parameters

• **Payload Geometry** –
  - Mass of Payload  80 kg
  - Length of Link $R_p$  0.2 m
  - Drag coefficient $C_{D_{pay}}$  1.05
  - Payload Area  0.16 m$^2$

• **Apparent Mass/Inertia Terms** –

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$A$</td>
<td>$0.913\rho R_l t^2(b/4)$</td>
<td>$I_F$</td>
<td>$0.872\rho (4c^4b/48\pi)$</td>
</tr>
<tr>
<td>$C$</td>
<td>$0.771\rho R_l t^2(c/4)$</td>
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• **Pitching moment damping coefficient of wing was assumed to be -1.864/rad.**
Drag Estimation

• Wing drag is calculated from empirical formulas –

\[ C_{D_w} = C_{D_p} + \frac{C_L^2}{\pi e AR} \]

\[ C_{D_p} = 0.0102 \quad e = 0.93 \]

\[ C_L = C_L(\alpha_w) \]

• Payload has a square cross sectional area

\[ C_{D_{pay}} = 1.05 \]
Plots of Aerodynamic Coefficients

Variation of $C_L$, $C_{Dw}$, and $C_M$ at 0.1 M for varying $\alpha_w$ in the linear range.

- $L/D$ reaches a maximum of 16.25 for an $\alpha_w$ close to 5 degrees.
- The wing-payload system is expected to trim close to this angle of attack.

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Time histories of various flight dynamic parameters for $\mu = -4.8^\circ$ and $m_p = 80$ kg

Initial Conditions –
- $u_c = 46$ m/s
- $w_c = 12$ m/s
- $H = 1000$ m
- $\theta_w = -10^\circ$
- $\theta_p = -7^\circ$
- $R_w = 2b$
Effect of varying Rigging angle
($\mu = -4.8^\circ$, $\mu = -5.0^\circ$ & $\mu = -5.5^\circ$)

- Initial conditions untouched and only rigging angle varied
- Increasing $\mu$
  - Increases $\alpha_w$
  - Decreases $\gamma$
  - Reduces range
- Decreases $u_c$, $w_c$ at which the system stabilizes
Change in Payload Mass

Effect of varying Payload mass 
(m_p = 40 kg, m_p = 60 kg & m_p = 80 kg)

- Initial conditions untouched and only payload mass varied
- Increasing m_p
  - Increases $\alpha_w$
  - Increases $\gamma$
  - Appears to have a damping effect on the system
Effect of varying Length of link \( R_w \) (\( R_w = 4.8 \text{ m} \) and \( R_w = 6.0 \text{ m} \))

- Initial conditions untouched and only length of wing link is varied
- Increasing length of wing link to 6 m seems to increase \( \alpha_w \) at which the system trims and hence is undesirable.
Effect of varying $C_{Mq}$ ($C_{Mq} = -1.864/rad, C_{Mq} = -18.64/rad$)

- Increasing this value by a factor of 10
  - Has no effect the flight dynamics of the system
  - Helps in reducing the amplitude of oscillations and hence a smoother flight
Summary

- 4-DOF longitudinal flight dynamic model used to determine trim and stability characteristics
- Aerodynamic coefficients computed by Euler solver; Drag coefficients estimated from empirical formulas
- Effect of apparent mass/inertia terms were included
- Simulations were run for time interval of 50 seconds with pre-specified initial conditions
- The wing-payload system showed good trim and stability characteristics for a rigging angle ($\mu = -4.8^\circ$) and payload weight ($m_p = 80$ kg).
- Effect of varying $\mu$, varying $m_p$, varying $R_w$ and increasing $C_{Mq}$ on the flight dynamics of the wing-payload system, with other parameters kept constant have been studied.
Thank You

Any Q’s?

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