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

2nd International Congress on Computational Mechanics and Simulation, 8th-10th December, 2006

Introduction

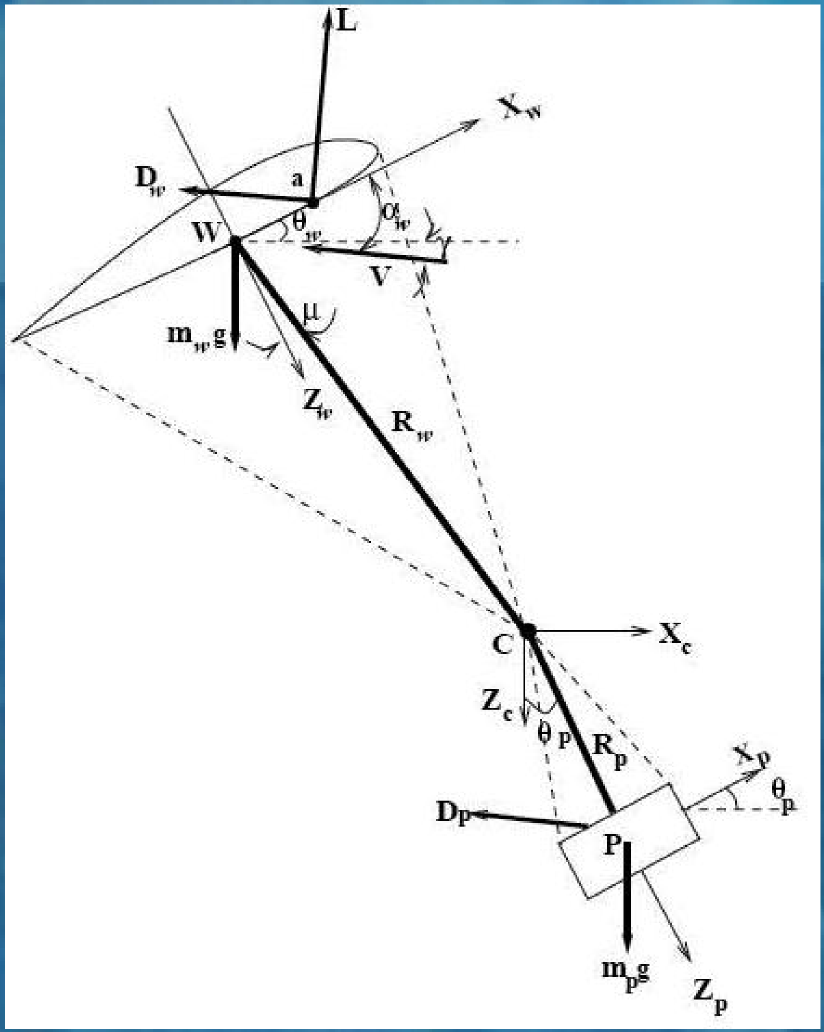
- Wing-payload systems
- Integrate the CFD solver with the Flight dynamics solver -

  → 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 Rw are important design parameters

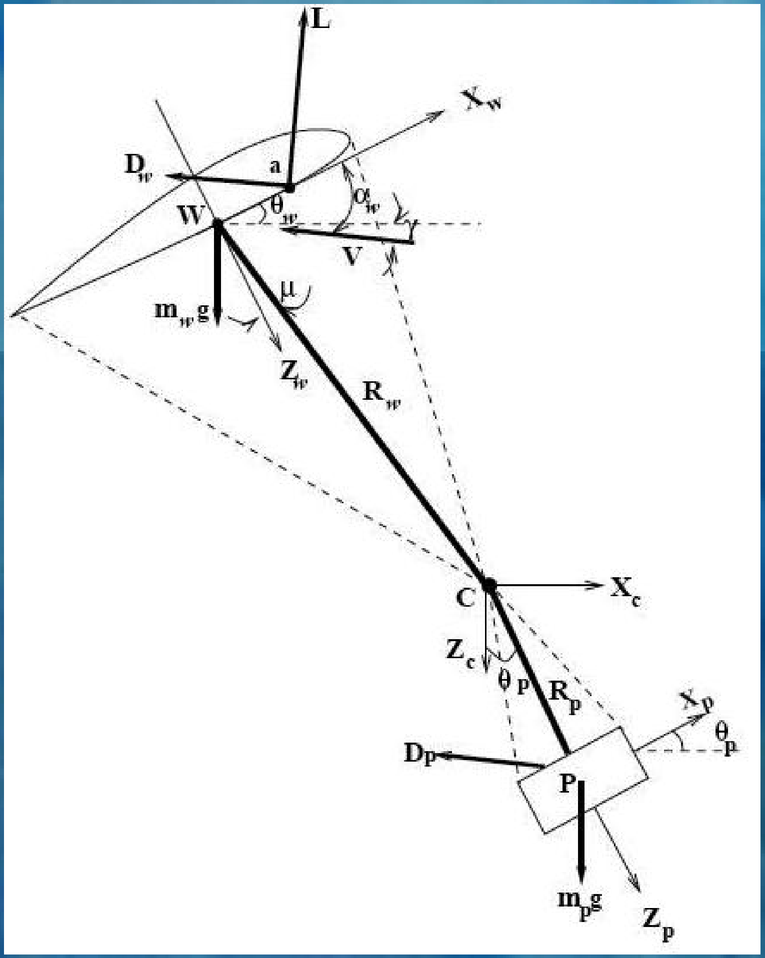


Assumptions

- 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

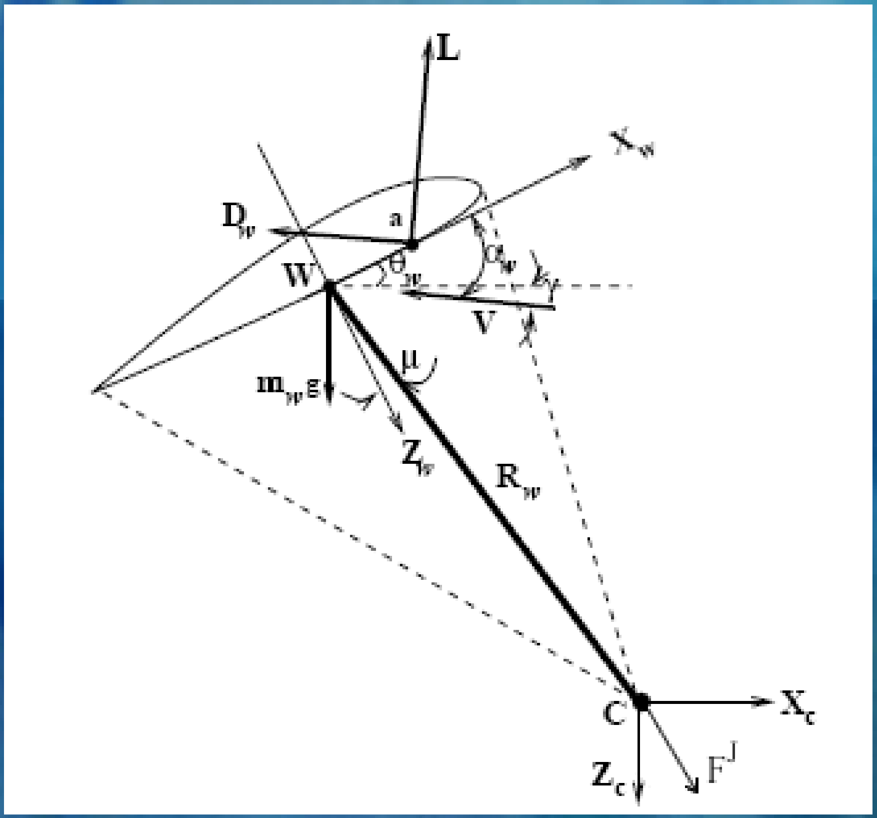
- Three body-fixed Cartesian co-ordinate axes -
  → Wing body-fixed axis system
  → Payload body-fixed axis system
  → Joint C body-fixed axis system
- Longitudinal dynamics of the system are characterized by u_c, w_c, θ_w, θ_p, q_w, q_p, α_w, μ and γ.
- 4-DOF model of wing-payload system is formed by deriving dynamic equations of -
  → Wing Submodel
  → Payload Submodel



Velocities and forces at joint C are assumed to be common

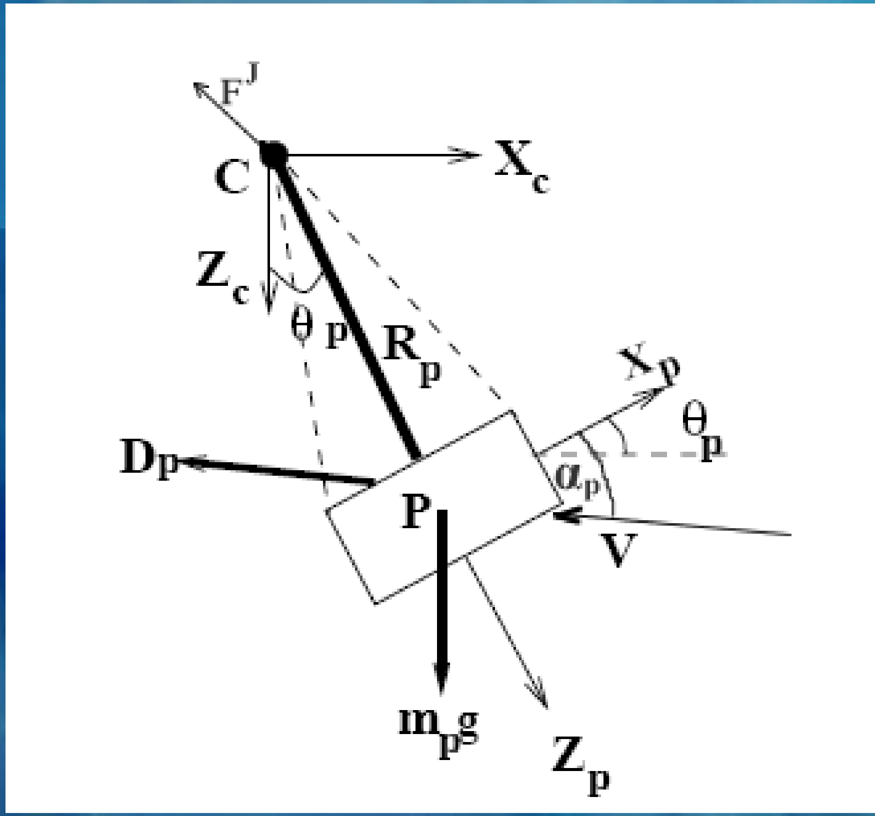
Wing Submodel

- **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



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

$$M\dot{\mathrm{x}} = B$$

which can be transformed into

$$\dot{\mathrm{x}} = M^{-1}B$$

equivalent to a dynamical system

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mu)$$

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.**

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_{Dpay} 1.05
  - Payload Area 0.16 m^2
- Apparent Mass/Inertia Terms –

Parameter	Value	Parameter	Value
A	$0.913\rho\pi t^2(b/4)$	I_F	$0.872\rho\,(4c^4b/48\pi)$
C	$0.771\rho\pi t^2(c/4)$		

- Pitching moment damping coefficient of wing was assumed to be -1.864/rad.

Drag Estimation

- Wing drag is calculated from empirical formulas –

$$C_{D_w} = C_{D_p} + \frac{C_L^2}{\pi\, e\, AR}$$

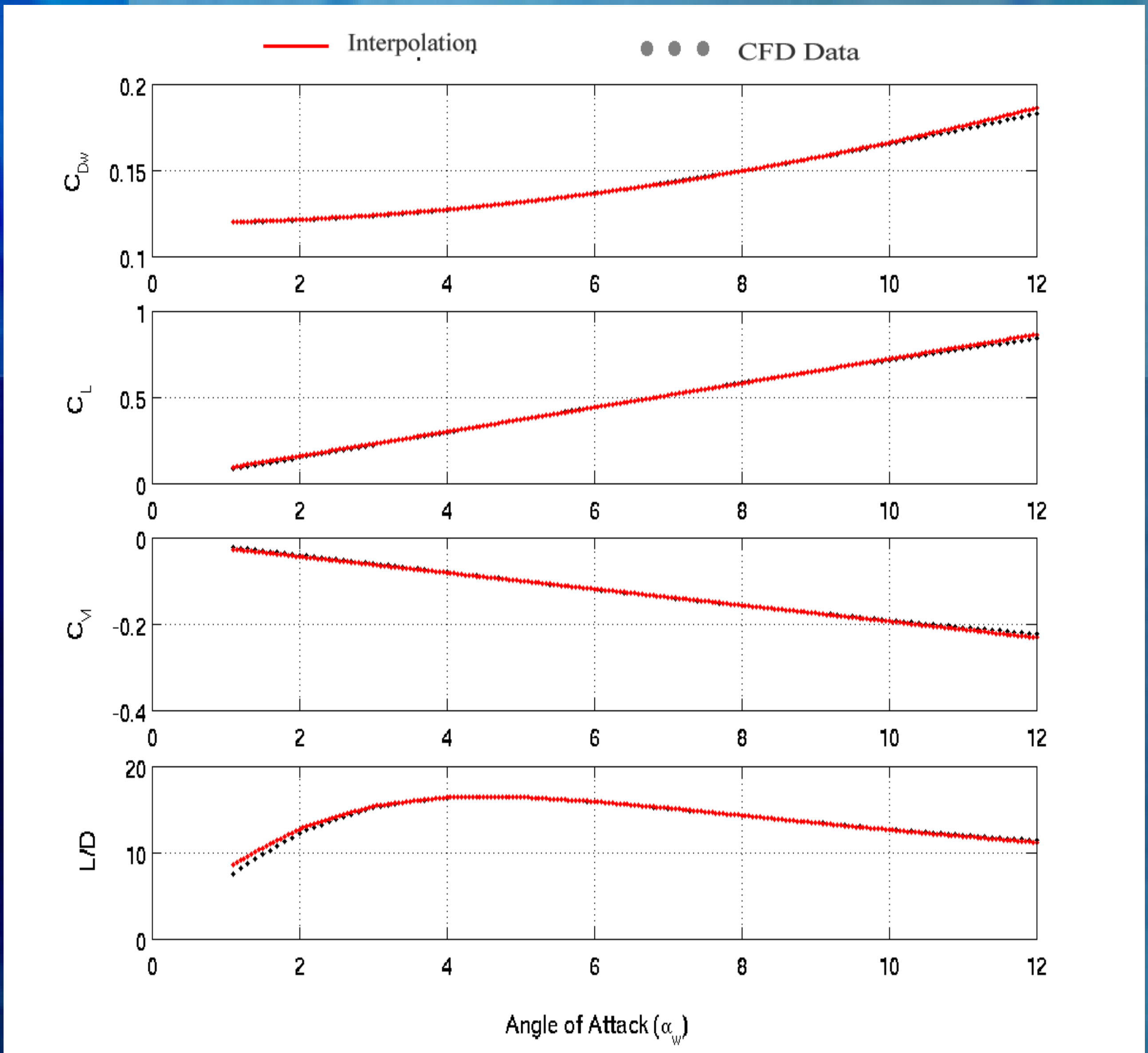
$$C_{D_p} = 0.0102 \qquad\qquad e = 0.93$$

$$C_L = C_L(\alpha_w)$$

- Payload has a square cross sectional area

$$C_{D_{pay}} = 1.05$$

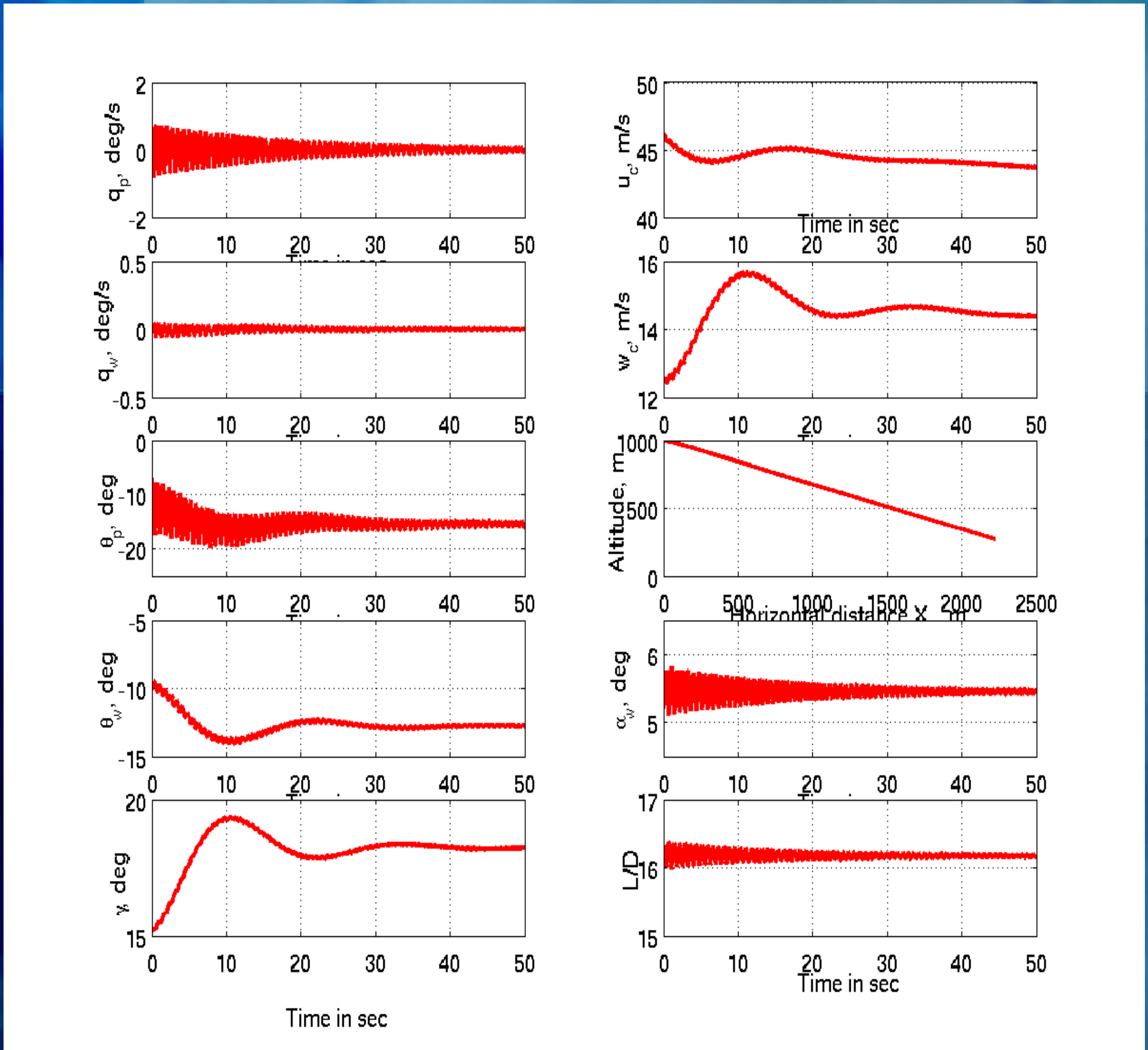
Plots of Aerodynamic Coefficients



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

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

Design Point Simulation

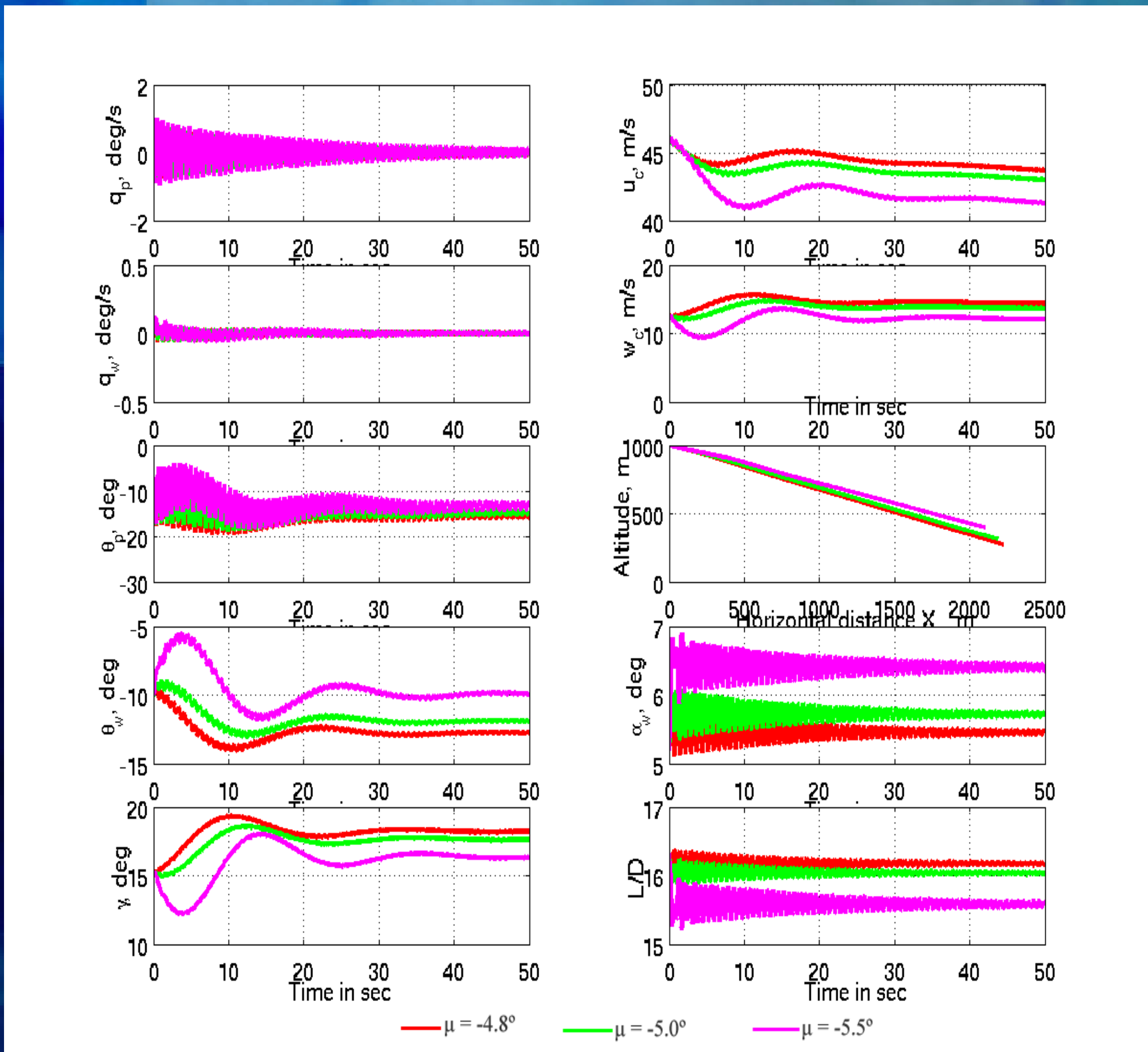


Time histories of various flight dynamic parameters for $\mu = -4.8^o$ and $m_p = 80$kg

Initial Conditions –

- $u_c = 46$ m/s
- $w_c = 12$ m/s
- H = 1000 m
- $\theta_w = -10^o$
- $\theta_p = -7^o$
- $R_w = 2b$

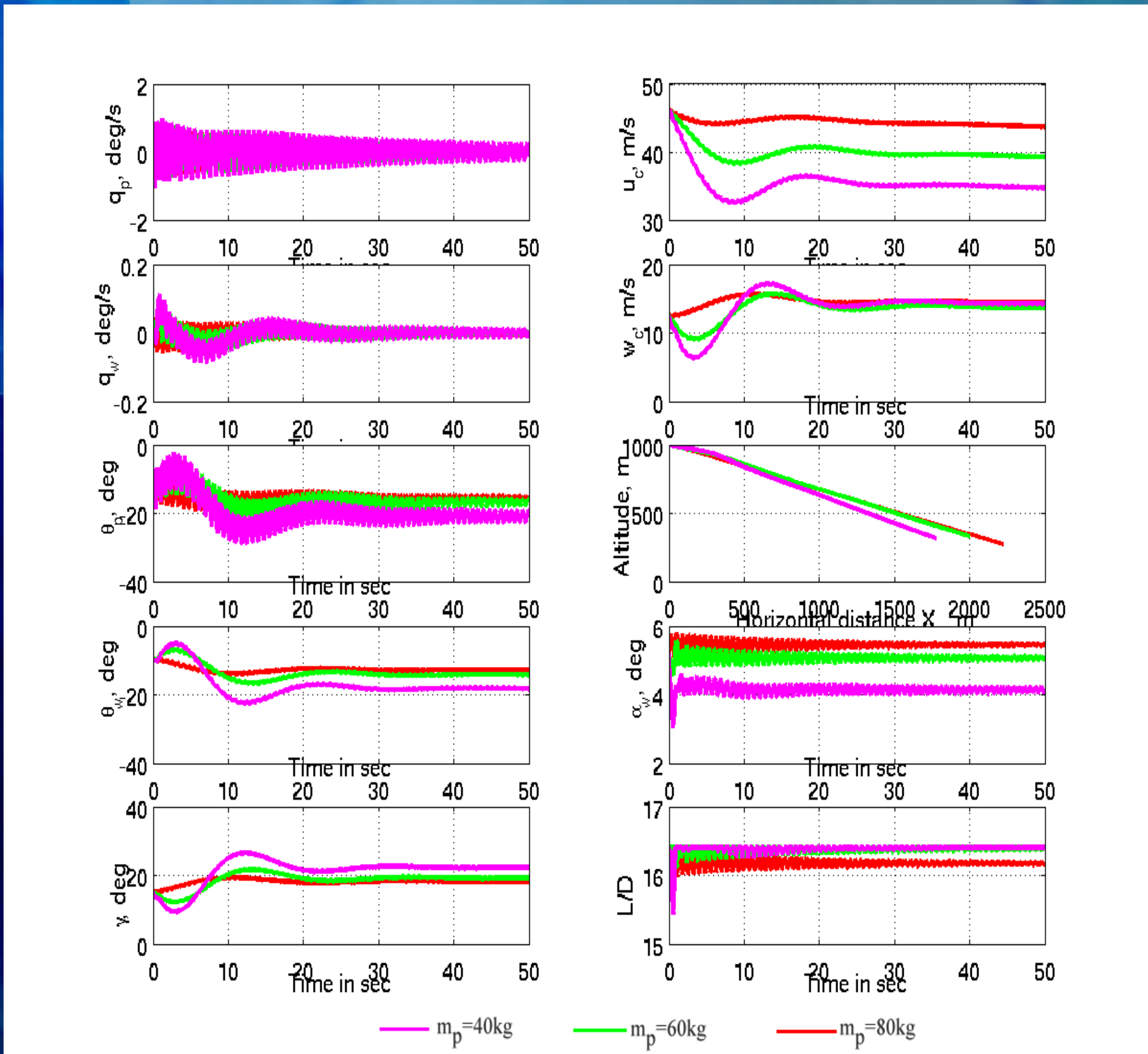
Change in Rigging Angle



Effect of varying Rigging angle (μ = -4.8°, μ = -5.0° & μ = -5.5°)

- Initial conditions untouched and only rigging angle varied
- Increasing μ
  - Increases α_w
  - Decreases γ
  - Reduces range
  - Decreases u_c, w_c at which the system stabilizes

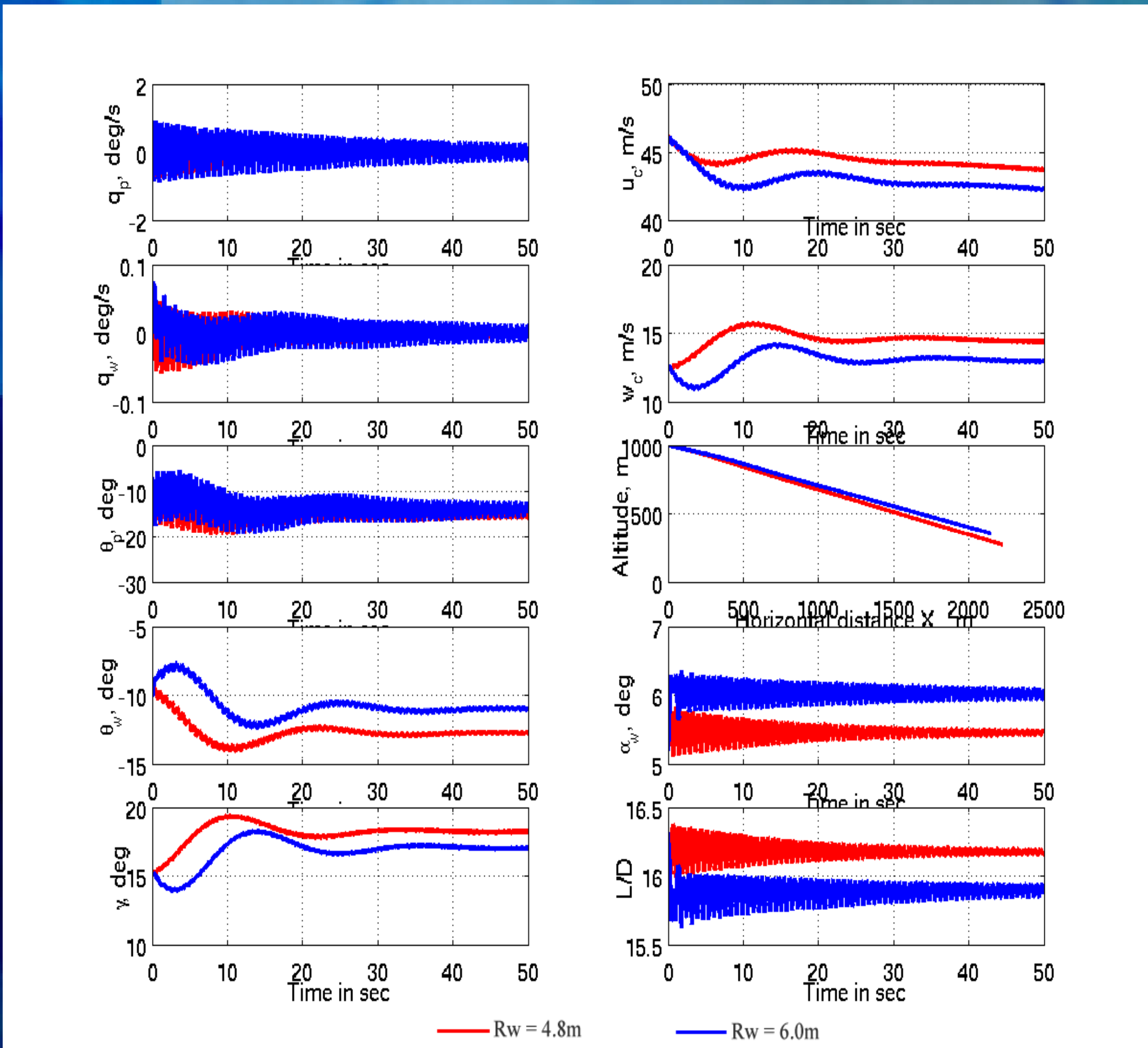
Change in Payload Mass



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 α_w**
  - **Increases γ**
  - **Increases range**
  - **Appears to have a damping effect on the system**

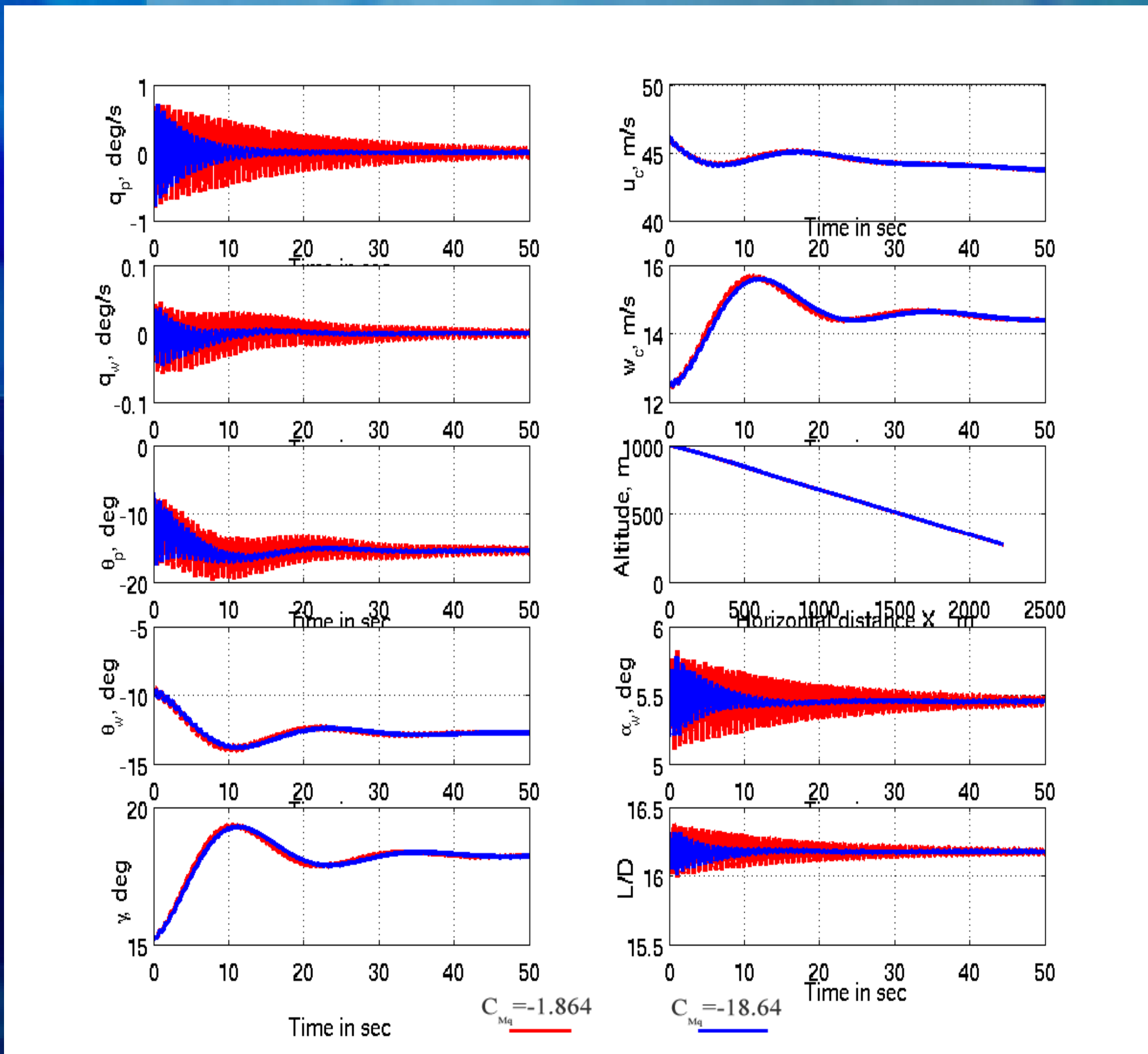
Change in Length of Link Rw



Effect of varying Length of link Rw (Rw= 4.8 m and Rw = 6.0 m)

- **Initial conditions untouched and only length of wing link is varied**
- **Increasing length of wing link to 6 m seems to increase α_w at which the system trims and hence is undesirable.**

Change in C_{Mq}



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 (μ = -4.8º) and payload weight (m_p = 80 kg).
- Effect of varying μ, 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 ?

☺