Dr.One

Friday, 27 June 2014

“Realizing a small UAV for medical transport in developing countries”

Master thesis: Ferdinand Peters

Definition

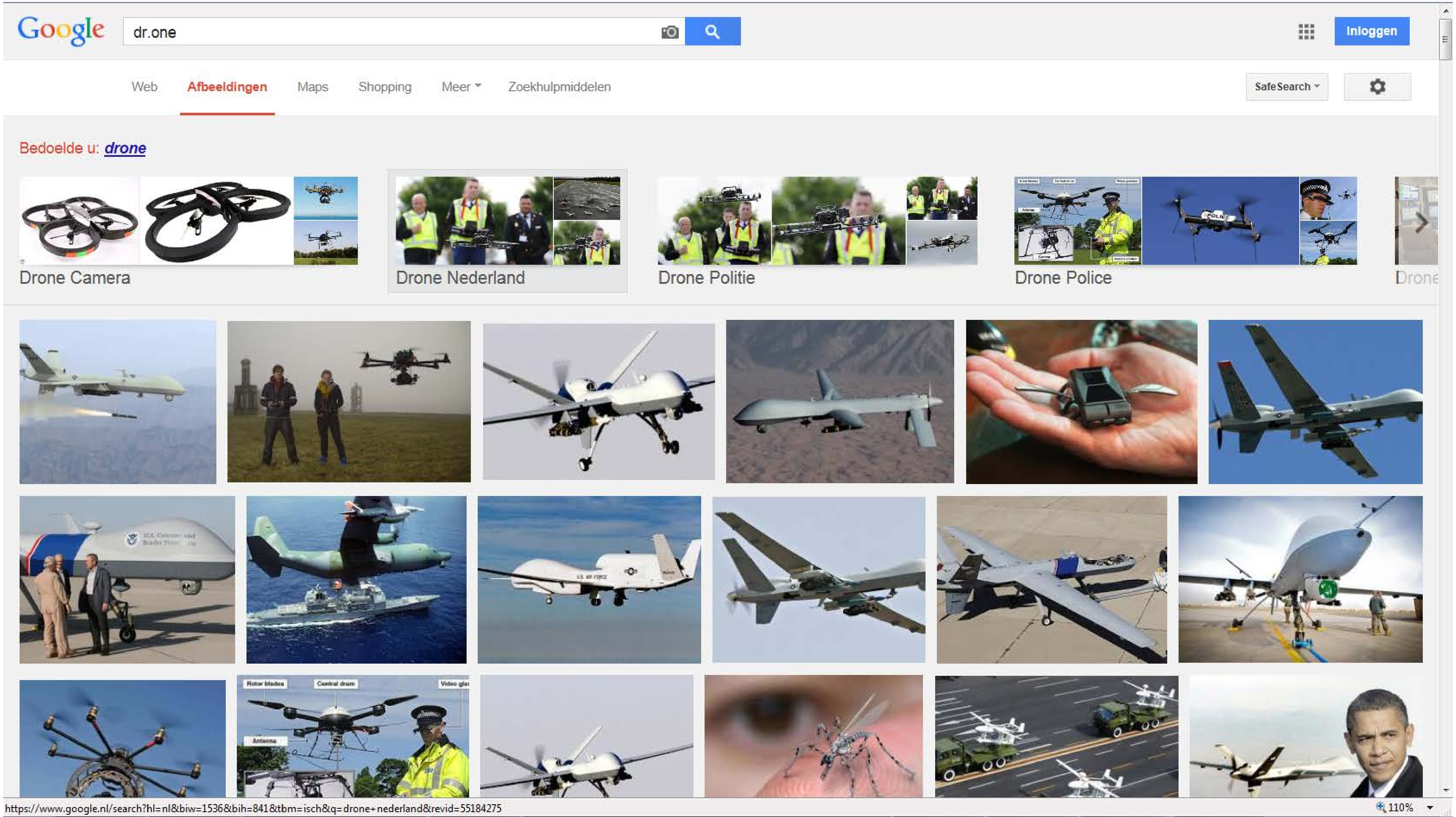
Drone (bee)

From Wikipedia, the free encyclopedia

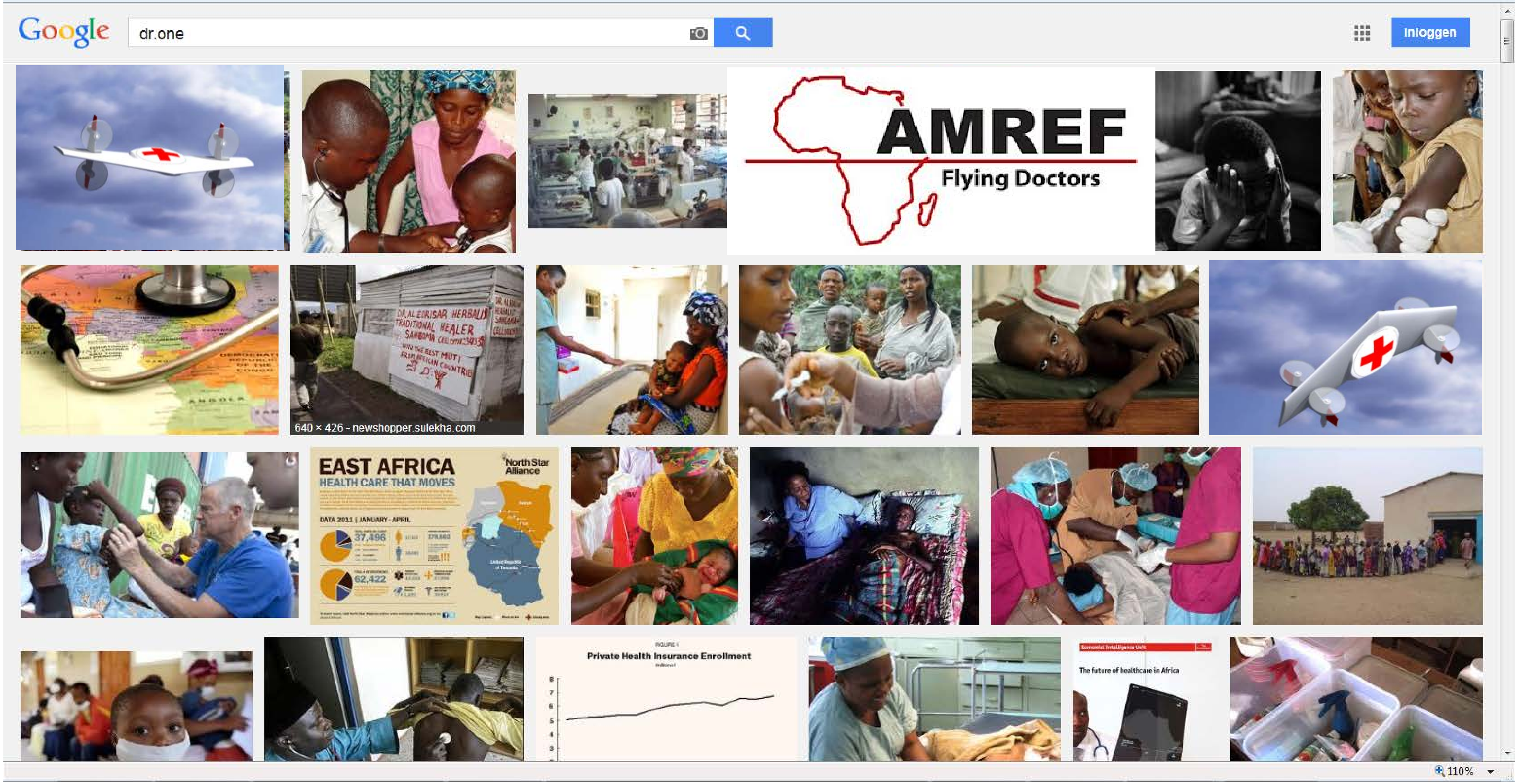
Drones are male honey bees. They develop from eggs that have not been fertilized, **and they cannot sting**.

In the 16th century it was given the figurative sense of **'idler**' or **'lazy worker**', as male bees make no honey, which is sometimes given as a folk etymology of the word 'drone' itself.

Google Search (present)



Google Search (future)



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"Realizing a small UAV for medical transport in developing countries"

Master thesis: Ferdinand Peters

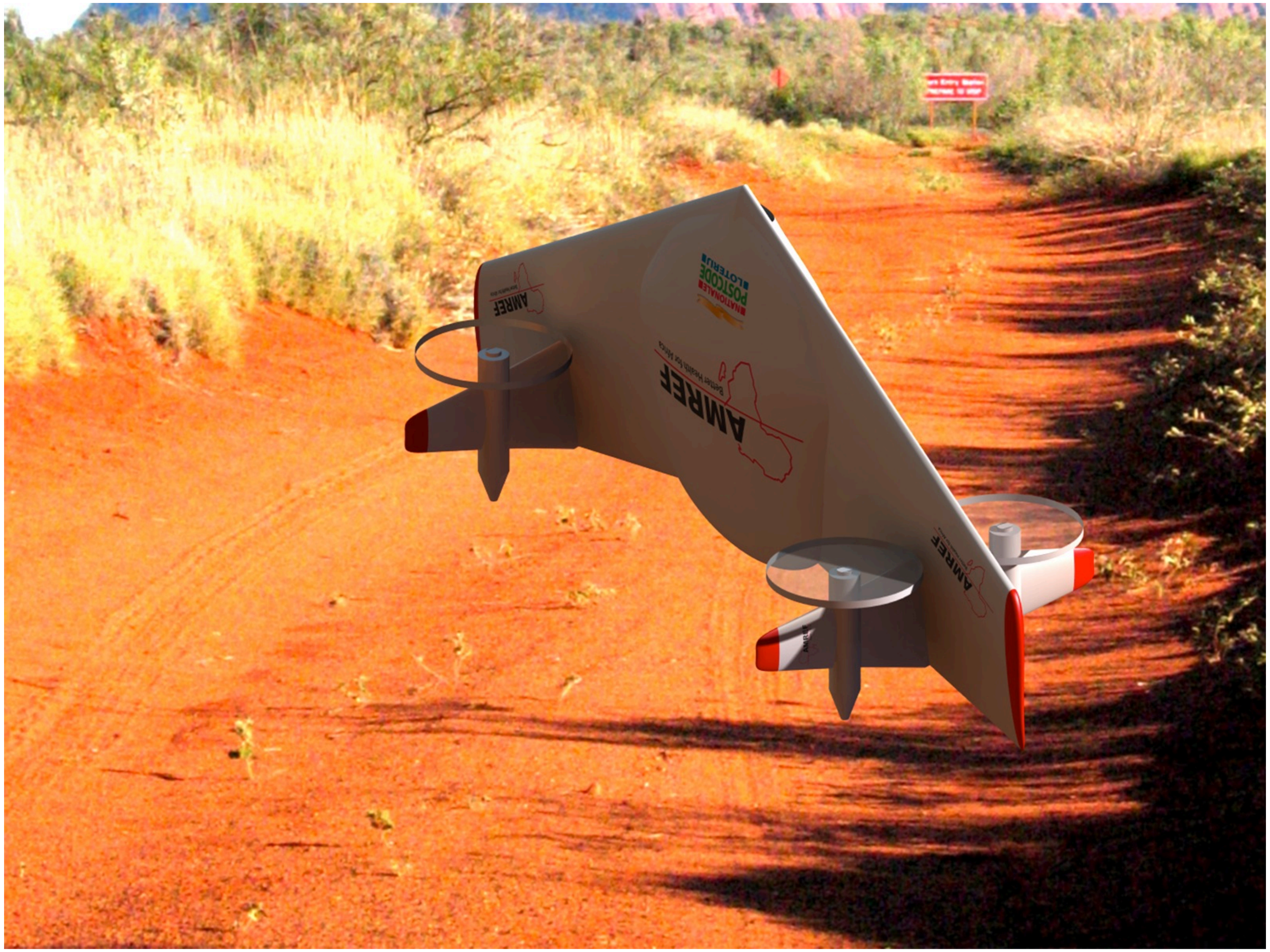
Outline presentation

- Problem definition
- Design
- Design Tool
    - Body
    - Wings
    - Propulsion
- Example design
- Dynamics & Control
    - Dynamic analysis
    - Control design

Problem Definition

Source: www.fayzwordz.wordpress.com

Problem Definition



Possible applications

- Urgent medical supply
- Final link in the supply chain
- Unreachable locations
- Blood sample collection & Lab on a chip

Design

Requirements

- Vertical take-off and landing (VTOL)
- Long range
- High flight speed
- Autonomous flight

Source: www.mikrokopter.de

- Mechanically simple
- Low cost
    - Unit
    - Maintenance
    - Manufacturing
    - Mechanically simple
- Locally produced and designed

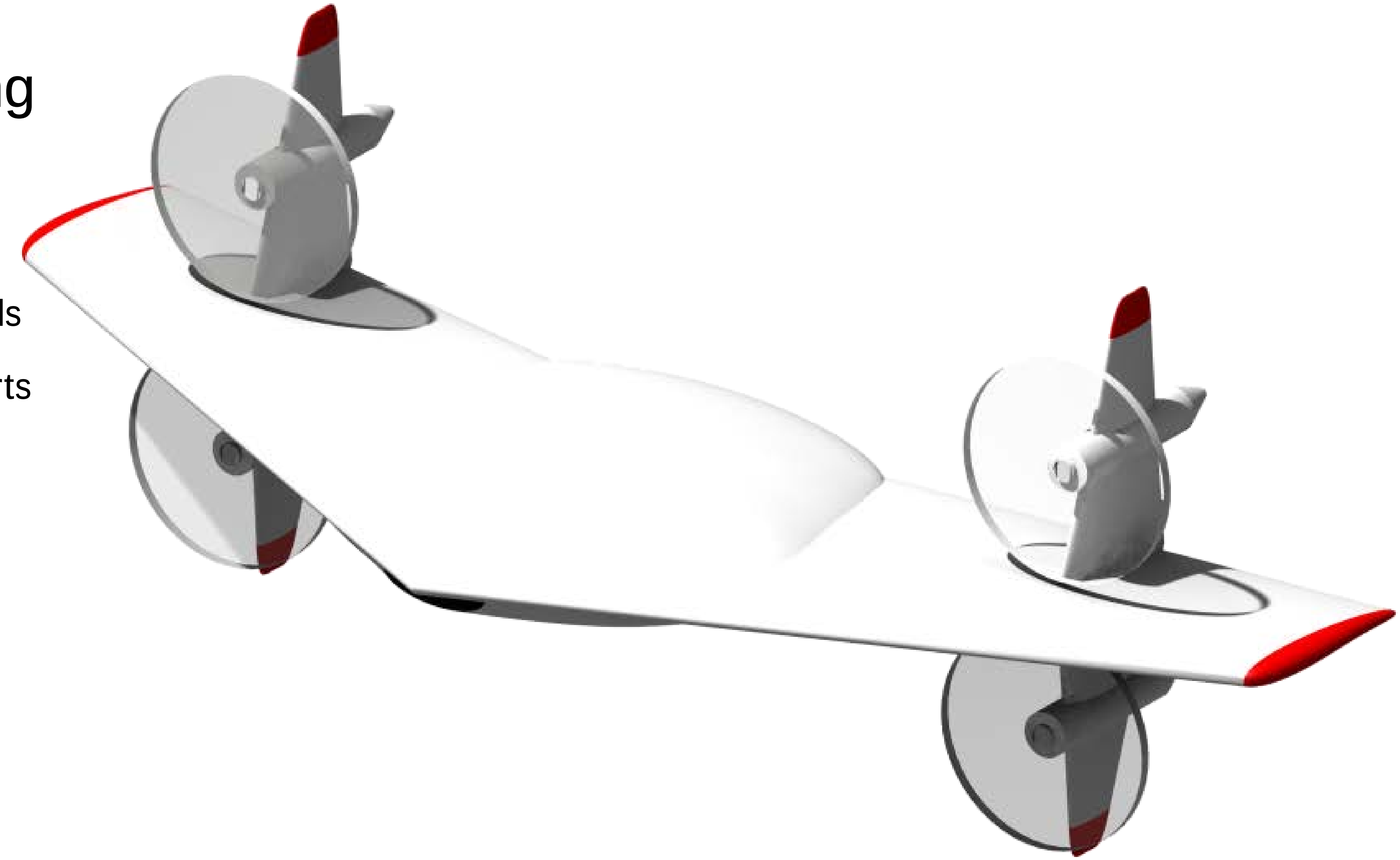
Source: www.unmannedgroup.com

Design

Chosen configuration

- 4 motor
- Hybrid flying wing
- Electric powered

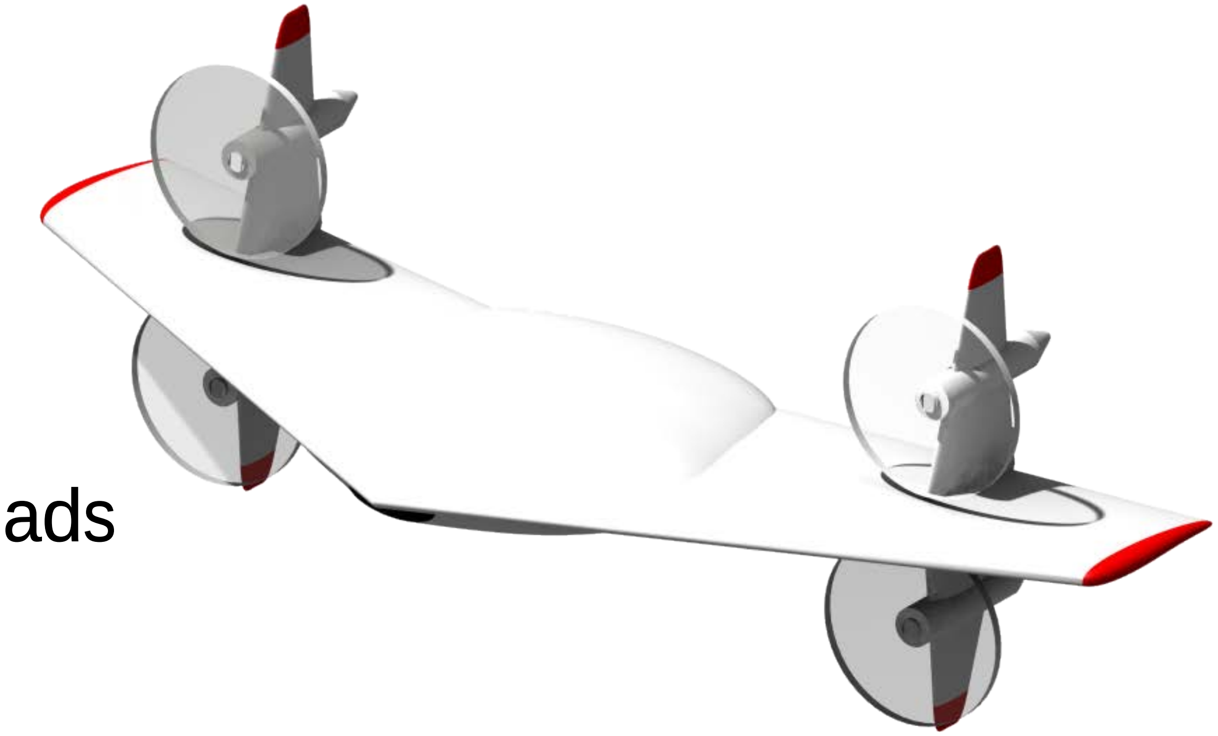
    - Inexpensive materials
    - Minimize moving parts



Design

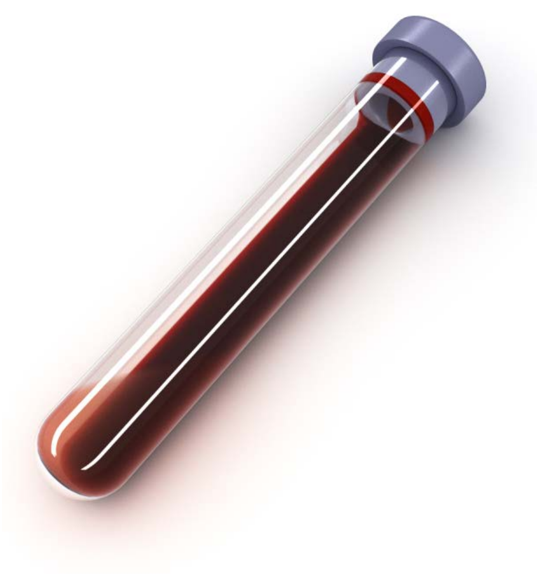
Flexible design

- Automatic sizing for different payloads



Source: mytransfusion.com

Source: aimlab.com

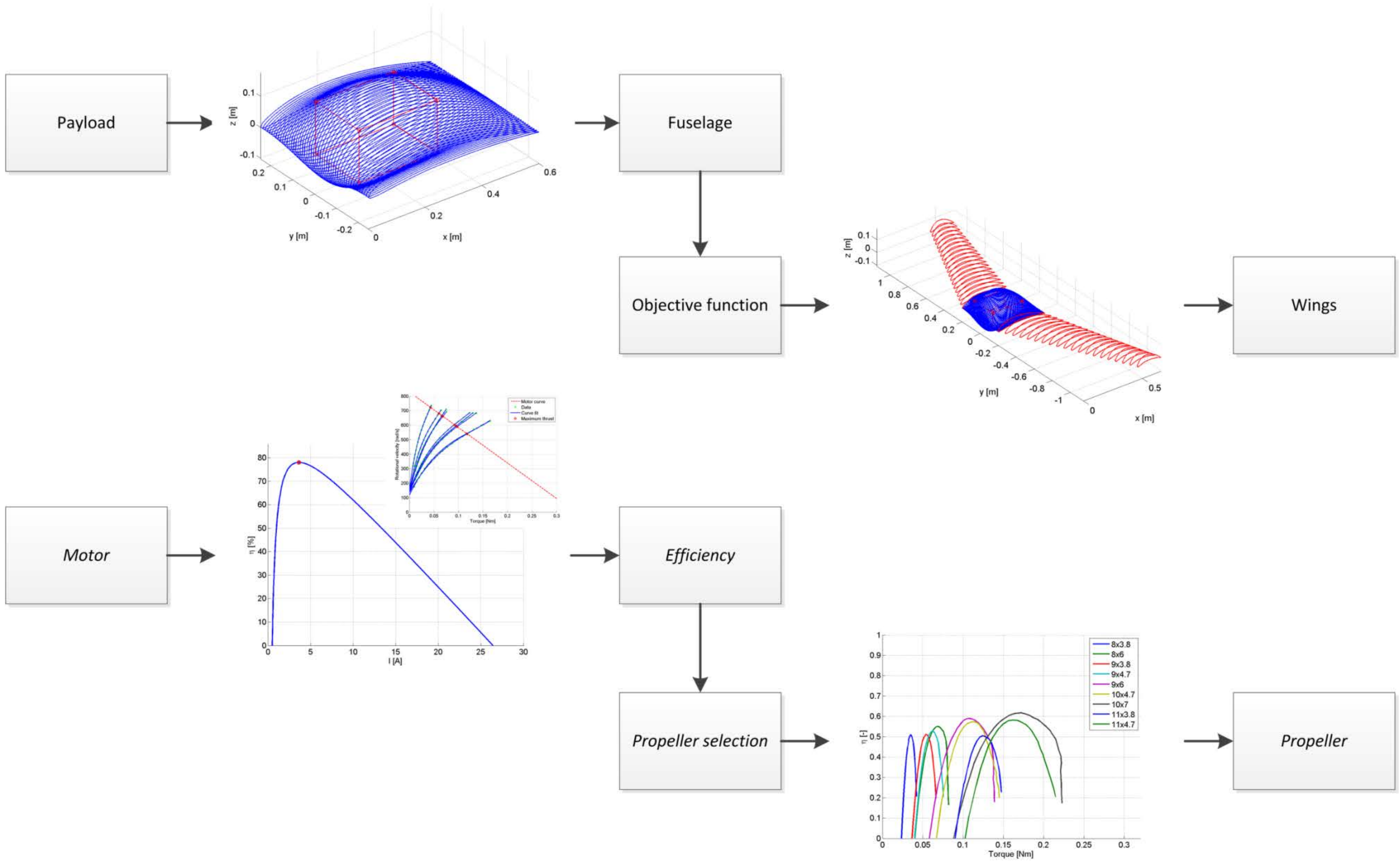


Source: http://www.npsg.uwaterloo.ca/

Design Tool

Main focus points

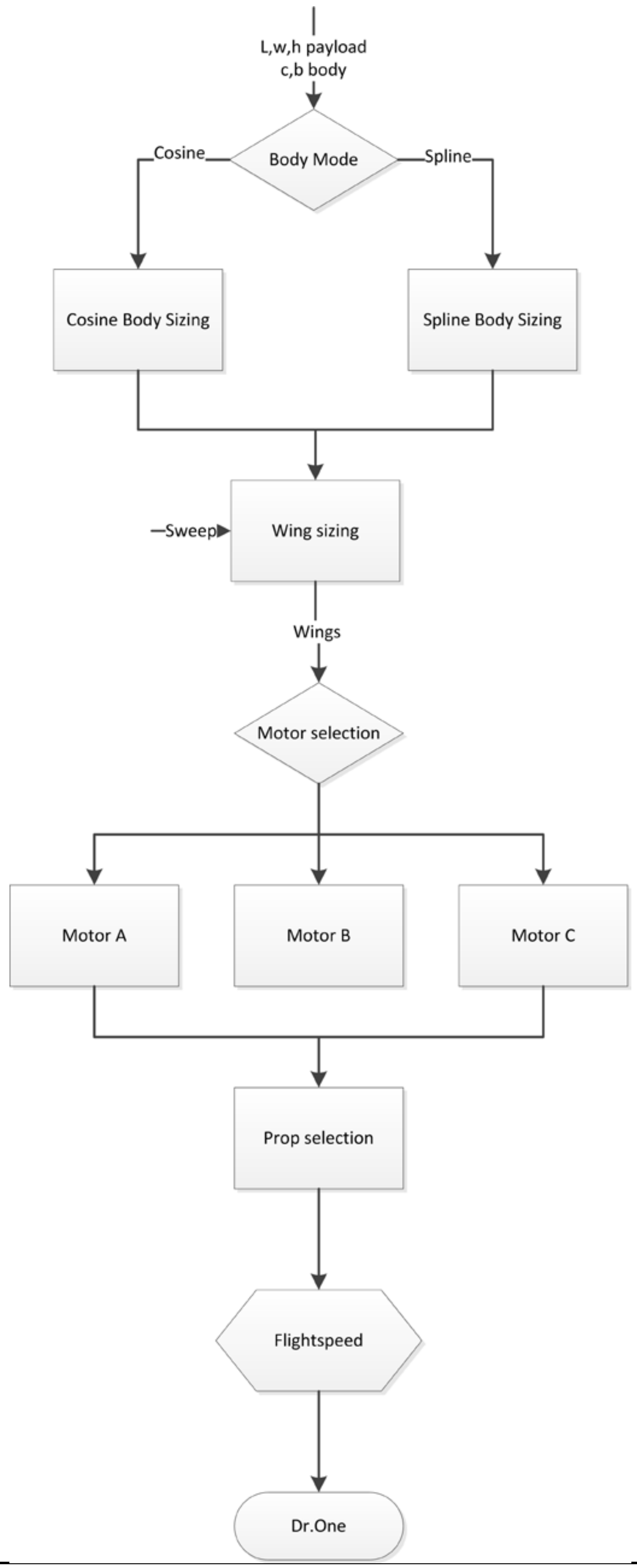
- Scalability
- Easy to use
- Modular approach
- Affordibility



Design Tool

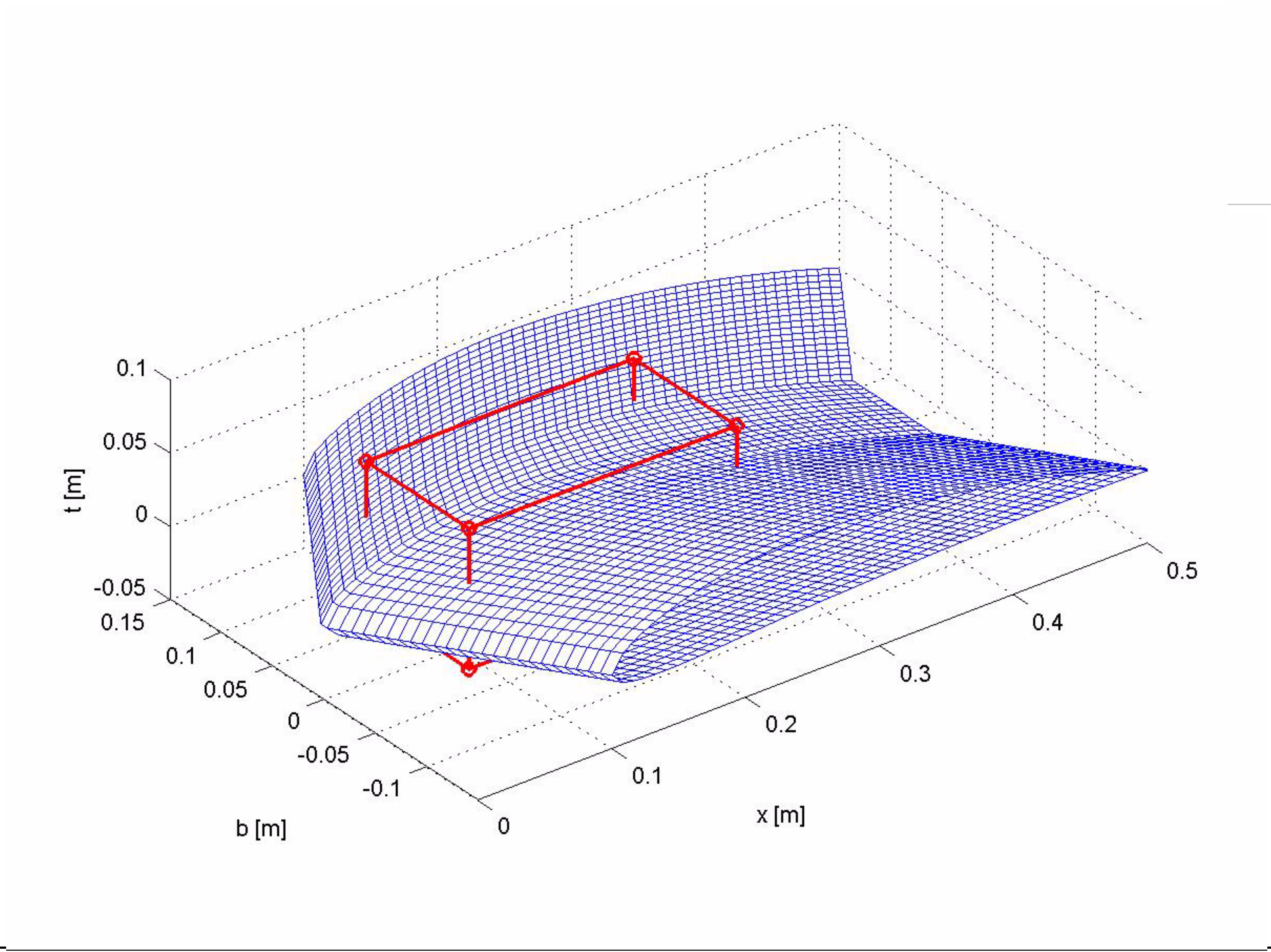
Sequence

- Body sizing
- Wing sizing
- Motor selection
- Propeller selection

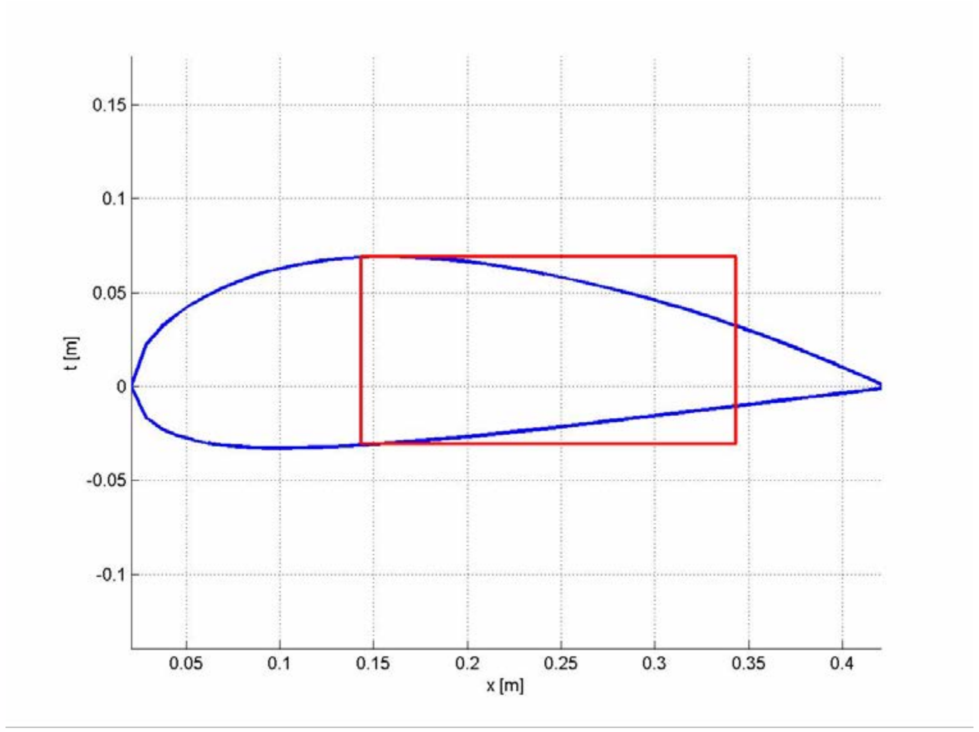


Body sizing

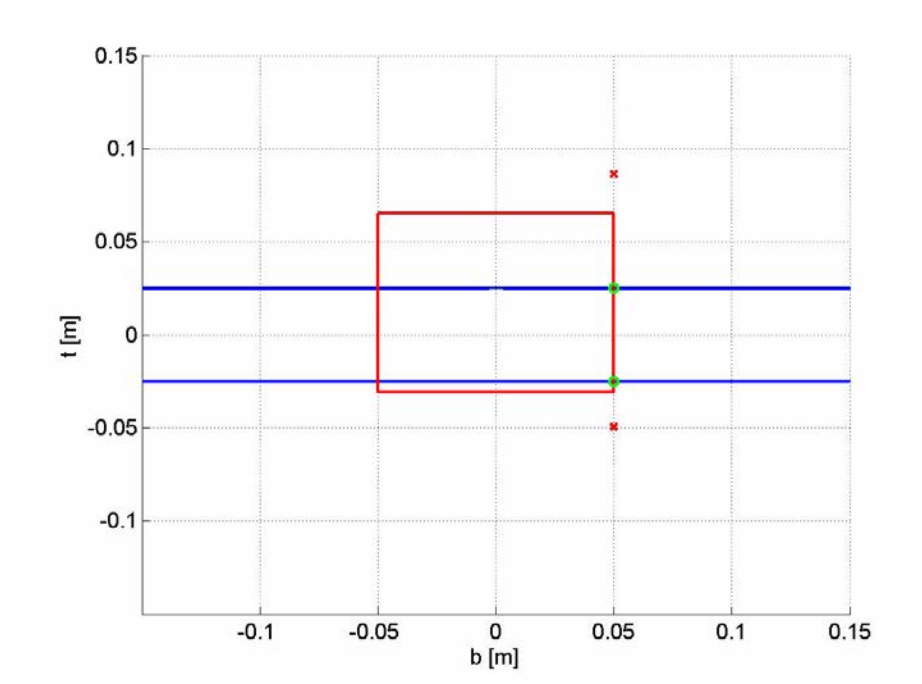
3D-Body



Side-plane

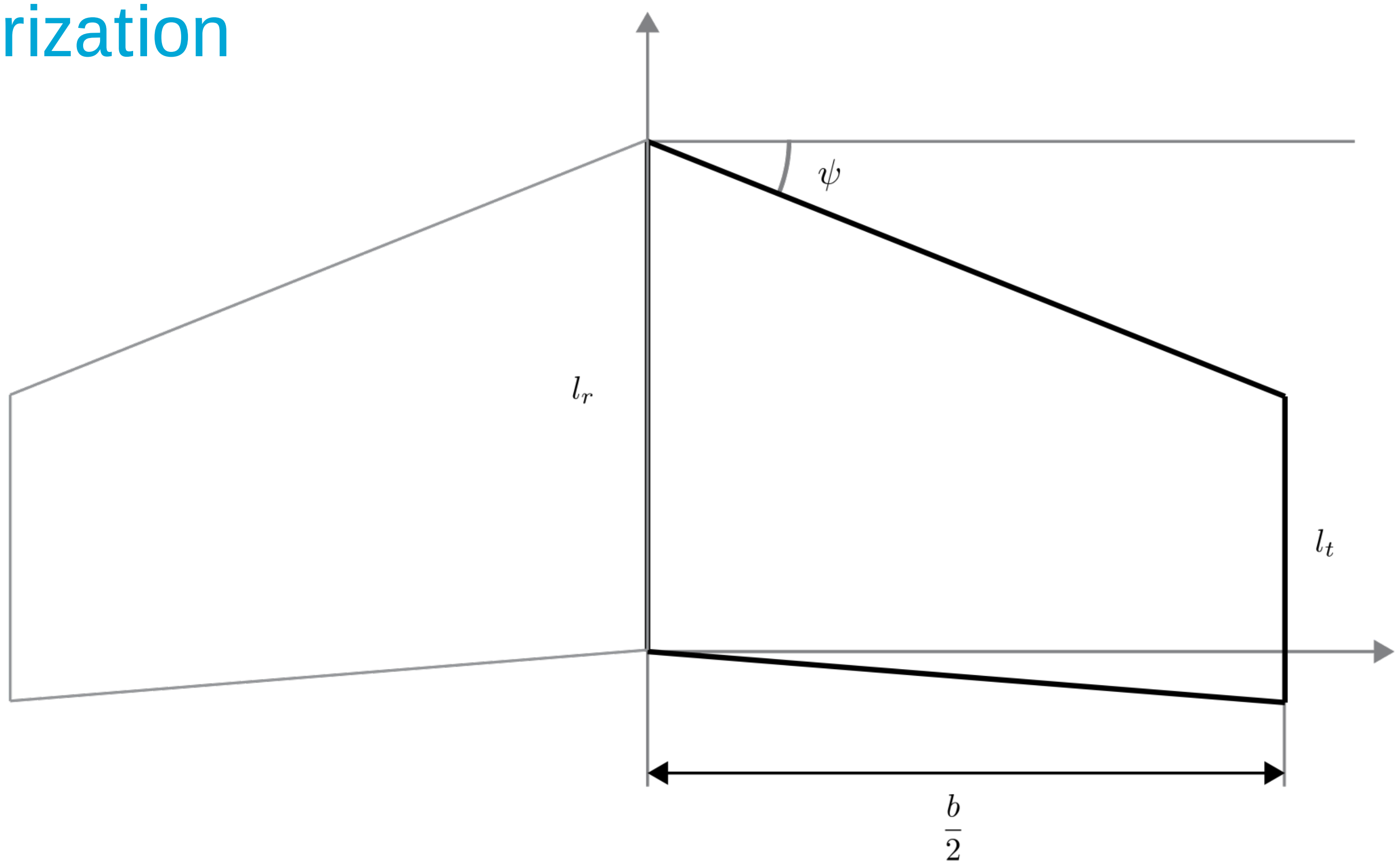


Front-plane: Cosine



Wing Sizing

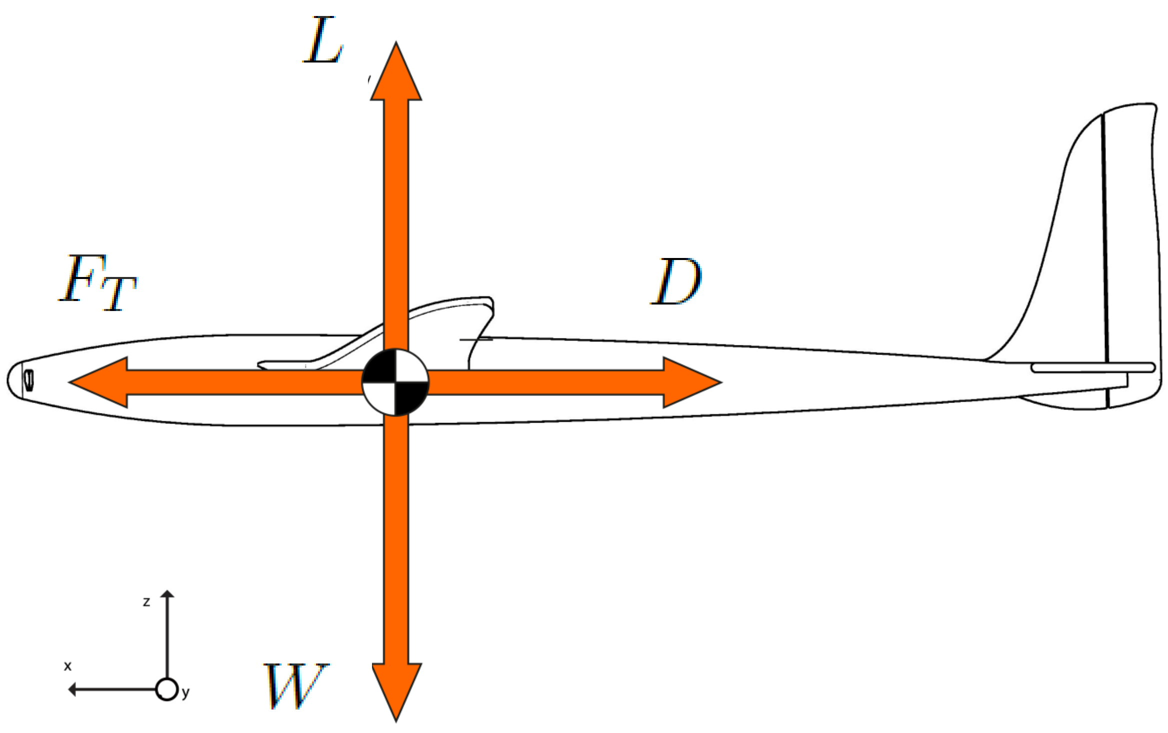
Parameterization



- l_r = chord at the root of the wing
- l_t = chord at trailing edge of the wing
- b = wingspan
- ψ = sweep angle

Wing sizing

Flight condition



$$\sum F_Z : L = W$$
$$\sum F_X : F_T = D$$

- L = lift force [N]
- D = drag force [N]
- W = total weight of the aircraft [N]
- F_T = total thrust of the propulsion [N]

Wing sizing

Objective function

$$D(lr, lt, b) = \frac{1}{2}\rho V^2 A C_d(Cl(W(lr, lt, b)))$$

Propulsion sizing

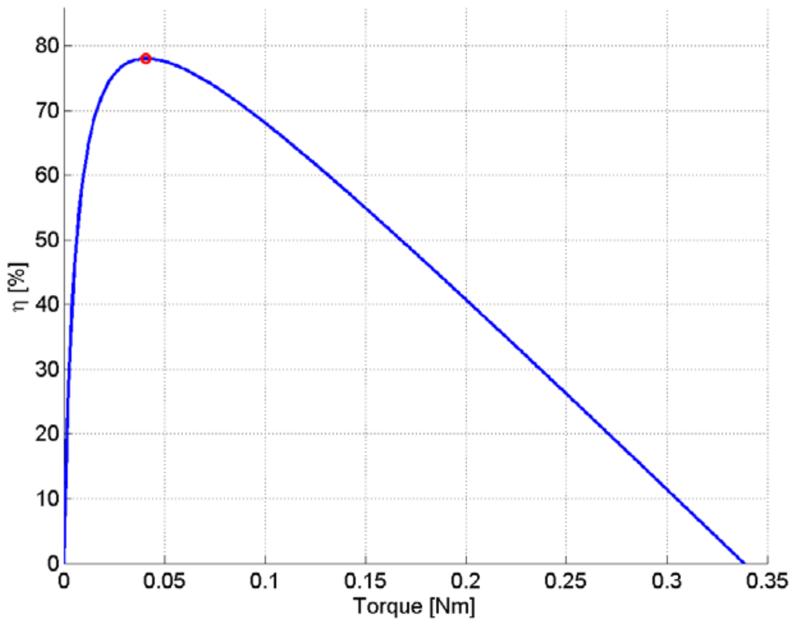
Motor performance characteristics

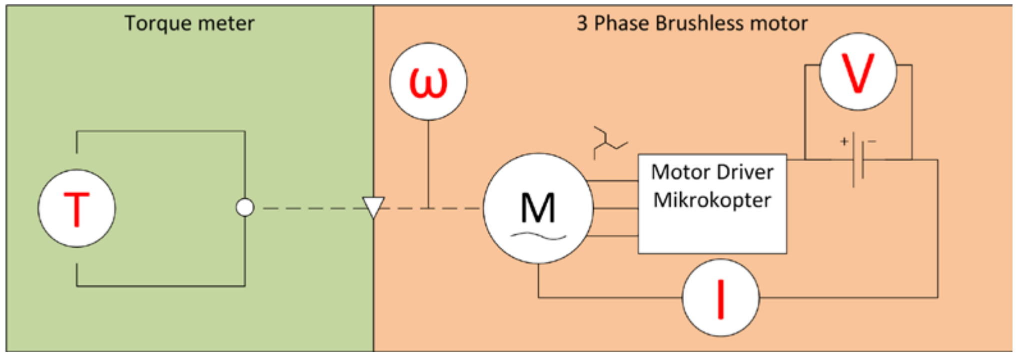
- Performance data can be acquired from the manufacturer

Not always available

- A test to determine experimentally.

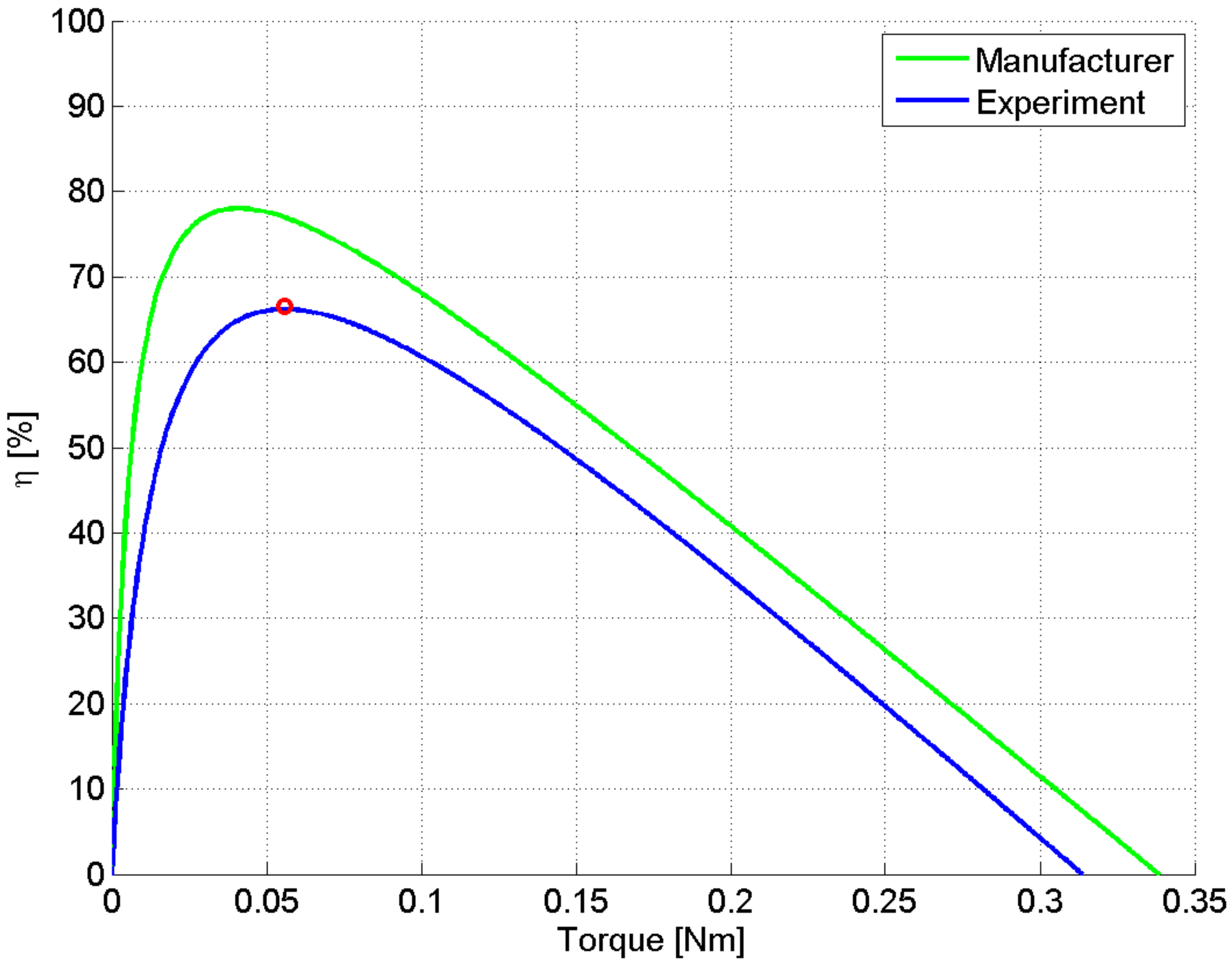
Source:mikrokopter.de





Motor Selection

Test comparison

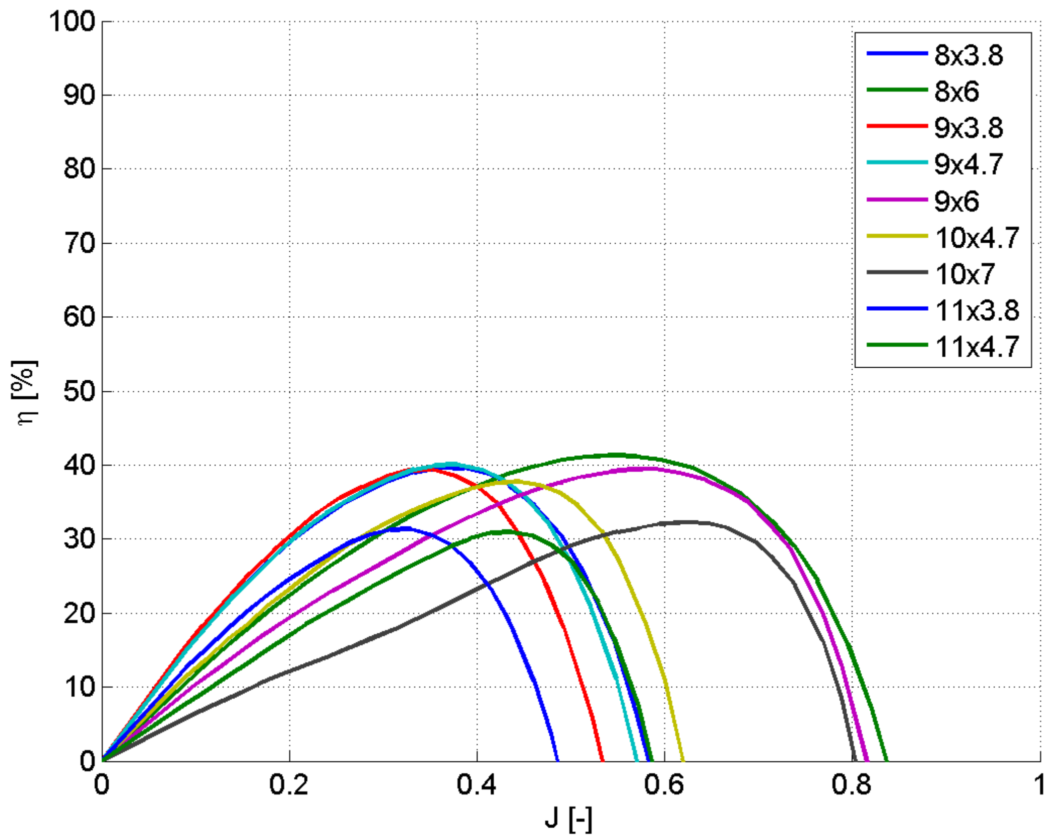


Propeller Selection

Propeller performance characteristics

- Windtunnel data

Source: http://aerospace.illinois.edu/

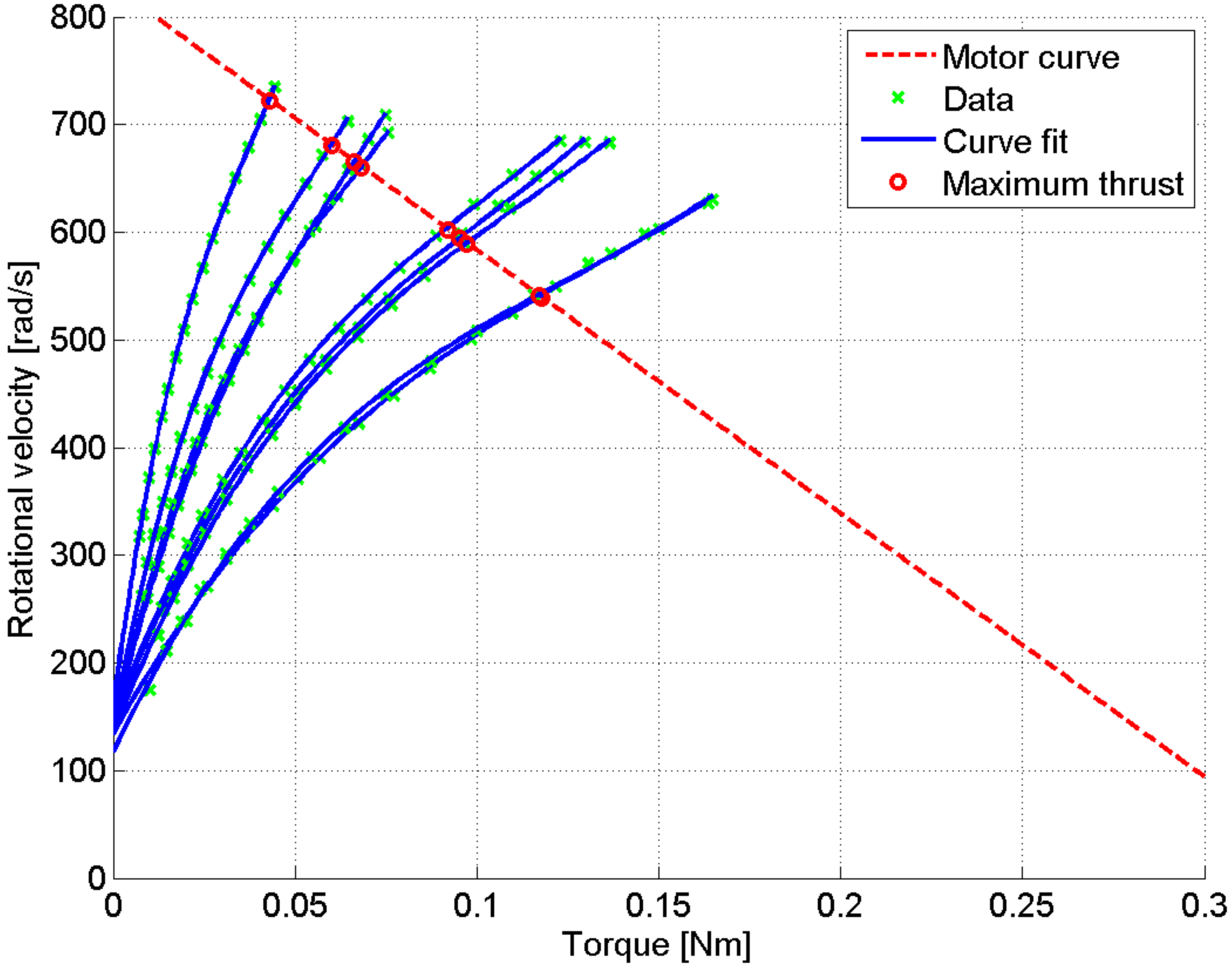


$$\eta_{prop} = J\left(\frac{C_T}{C_P}\right)$$

$$J = \frac{V}{\omega d}$$

Propeller Motor matching

Static



prop	T [g]	T_{tot} [kg]
8x3.8	281	1.12
8x6	235	0.94
9x3.8	400	1.60
9x4.7	382	1.53
9x6	315	1.26
10x4.7	465	1.86
10x7	385	1.54
11x3.8	673	2.69
11x4.7	568	2.27

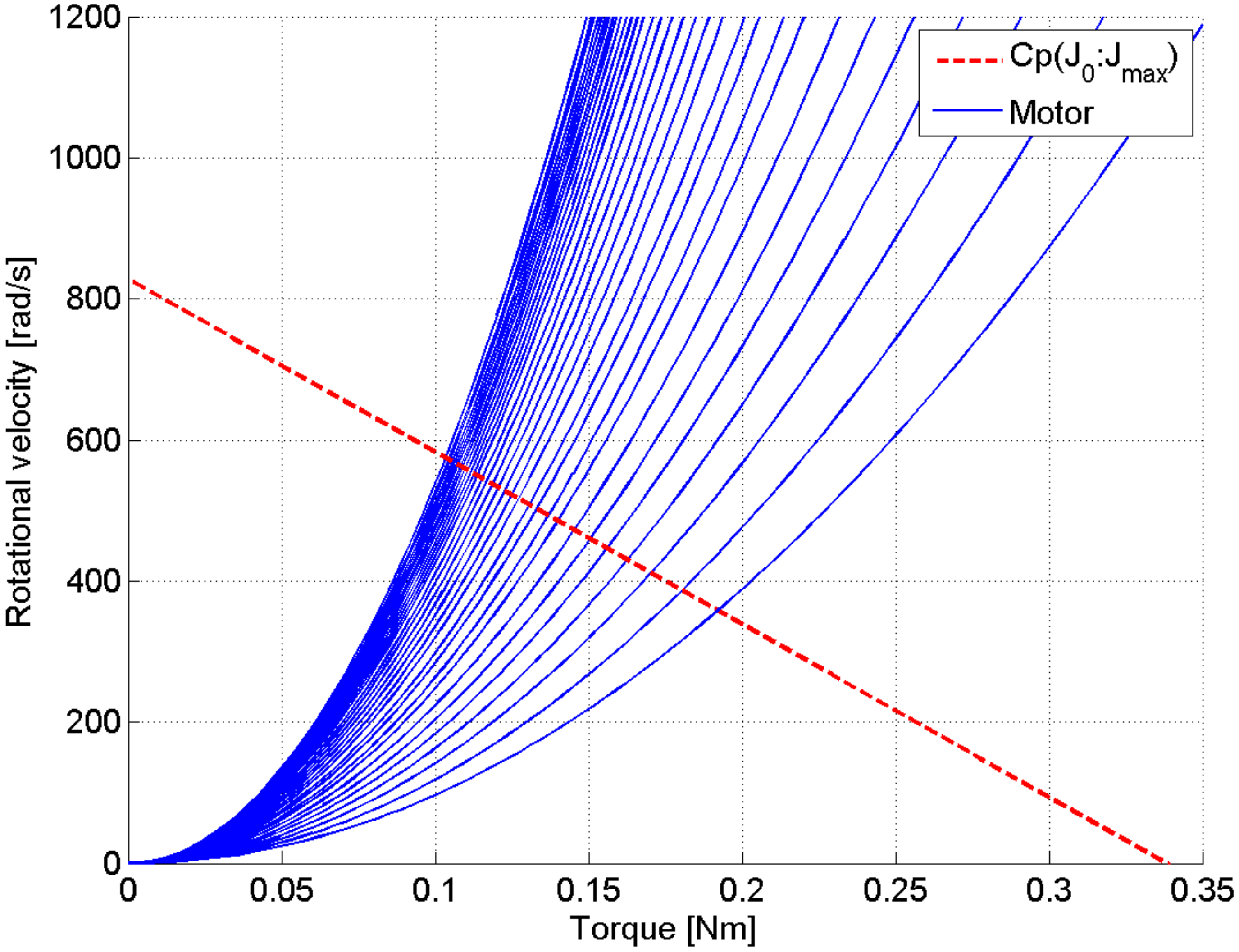
Static thrust with Robbe Roxxy

Propeller Motor matching

Dynamic

$$Q_{prop} = \frac{C_p}{2\pi}\rho\omega^2 d^5$$

$$Q_m = -a_\omega \omega + b_\omega$$



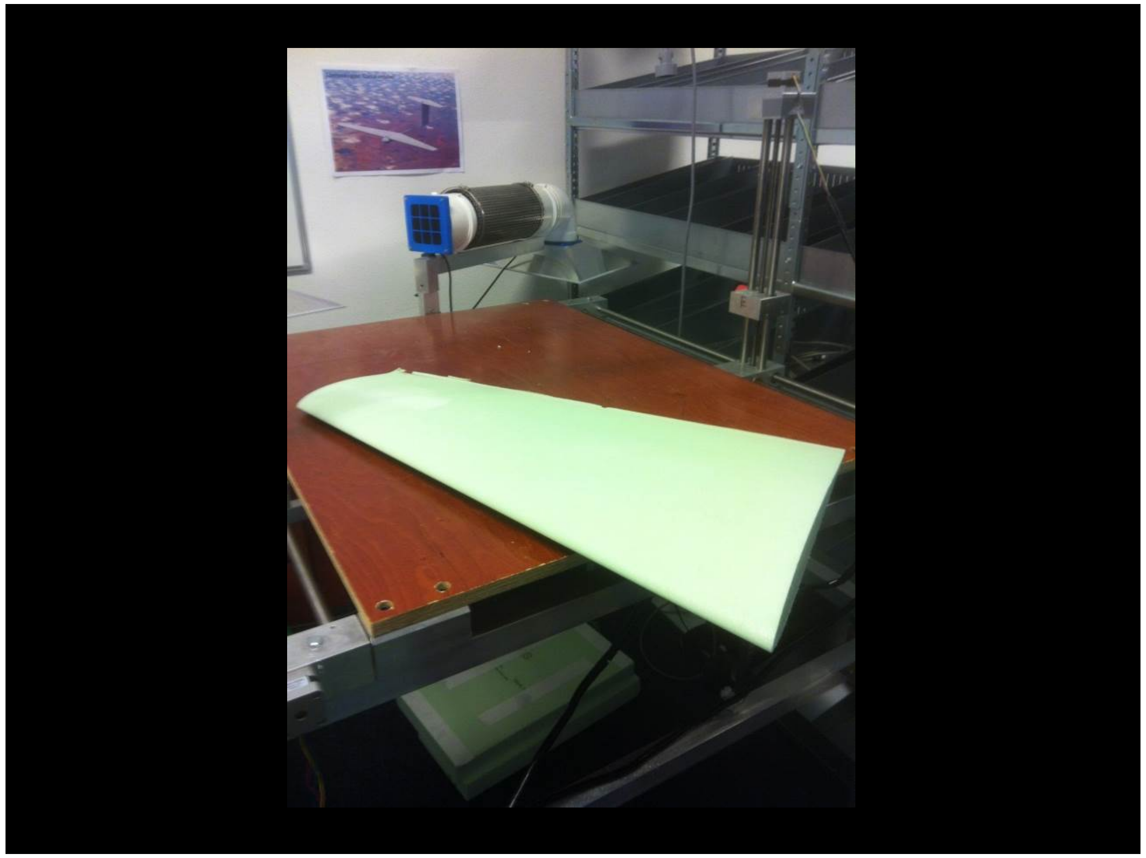
Example design

GUI

- Are you ready to design your first Dr.One?

Production

3D-milling & hot wire cutter



Outline presentation

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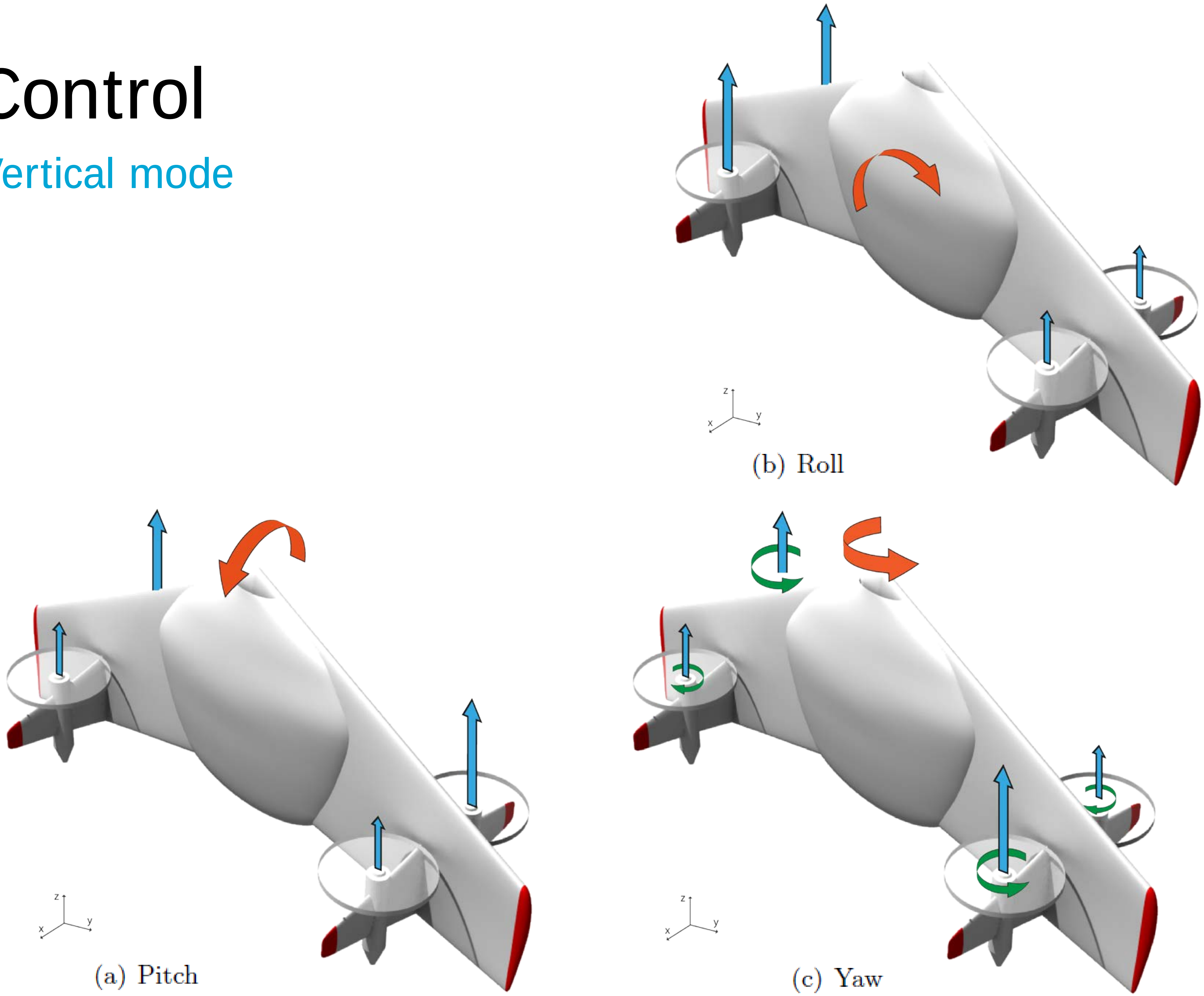
    - Dynamic analysis
    - Control design
    - Validation of dynamic model

Control

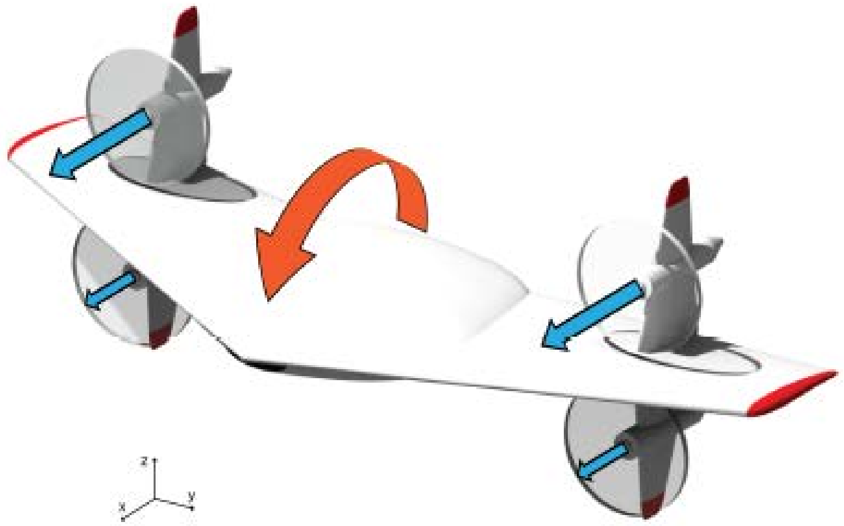
Vertical mode



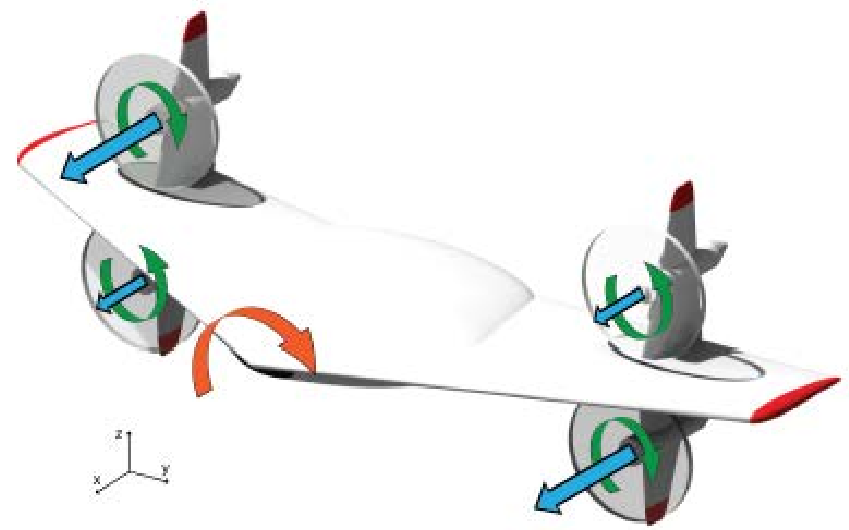
(a) Pitch (b) Roll (c) Yaw

Control

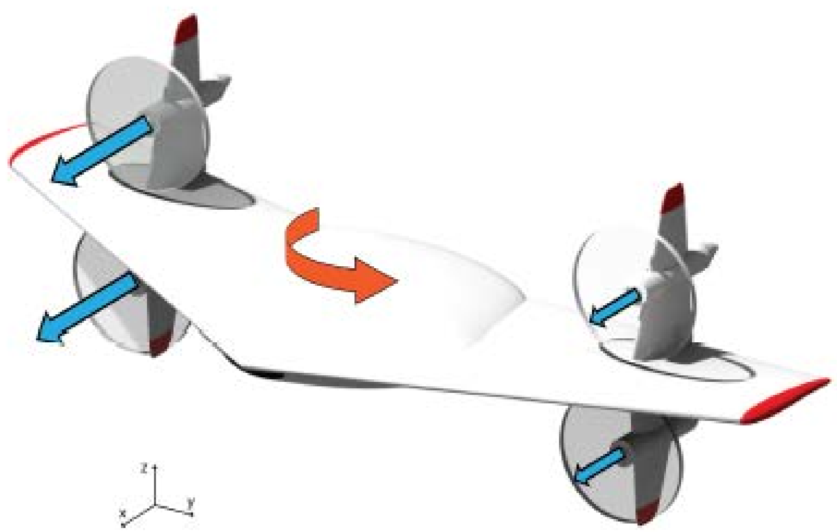
Horizontal mode



(a) Pitch



(b) Roll



(c) Yaw

Control design

Possible control loop

- PID Feedback controller
- Input: 4 rotational velocities
- Output: 12 states (3 translations, 3 rotations and their velocities)

Dynamic model

Modified model by Skander Tamallaah (NLR)

Rigid body dynamics

$$\mathbf{Y_{rb}} = \begin{bmatrix} \mathbf{x} \\ \mathbf{q} \\ \mathbf{v} \\ \omega \end{bmatrix} \qquad \begin{aligned} \mathbf{q} &= \begin{bmatrix} \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 \end{bmatrix} \\ \mathbf{v} &= \dot{\mathbf{x}} \end{aligned}$$

$$\dot{\mathbf{Y}}_{\mathbf{rb}} = \begin{bmatrix} \dot{\mathbf{x}} \\ \dot{\mathbf{q}} \\ \dot{\mathbf{v}} \\ \dot{\omega} \end{bmatrix}$$

$$\dot{\mathbf{x}} = \mathbf{v}$$

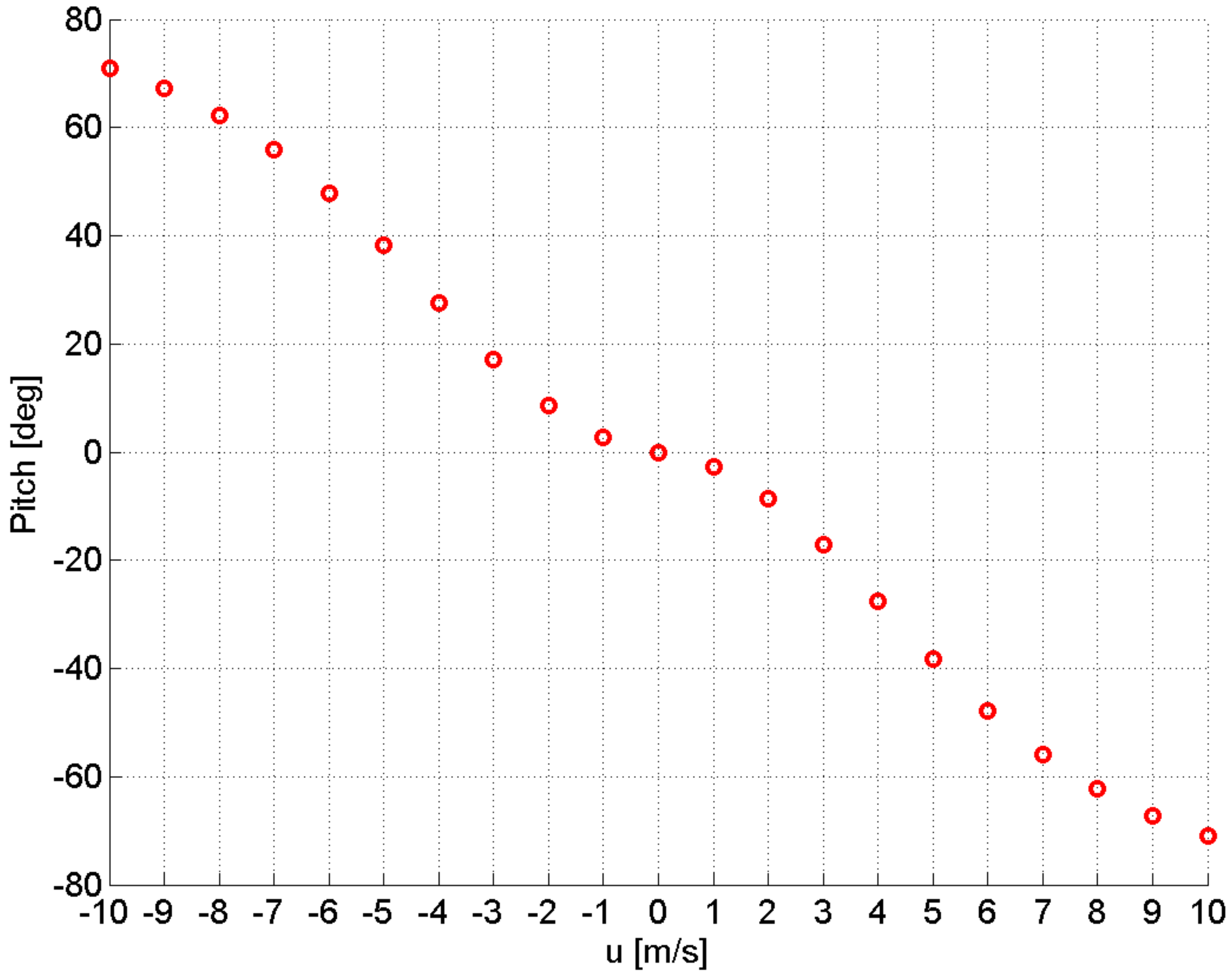
$$\dot{\mathbf{q}} = \frac{1}{2} \begin{bmatrix} \lambda_0 & -\lambda_1 & -\lambda_2 & -\lambda_3 \\ \lambda_1 & \lambda_0 & -\lambda_3 & \lambda_2 \\ \lambda_2 & \lambda_3 & \lambda_0 & -\lambda_1 \\ \lambda_3 & -\lambda_2 & \lambda_1 & \lambda_0 \end{bmatrix} \begin{bmatrix} 0 \\ \omega \end{bmatrix}$$

$$\dot{\mathbf{v}} = \sum \mathbf{F} (\mathbb{M})^{-1}$$

$$\dot{\omega} = \mathbf{J}^{-1} \left(\mathbb{M}_{\mathbb{G}} - \omega \times (\mathbf{J} \cdot \omega) \right)$$

Dynamics Analysis

Trim



Dynamics Analysis

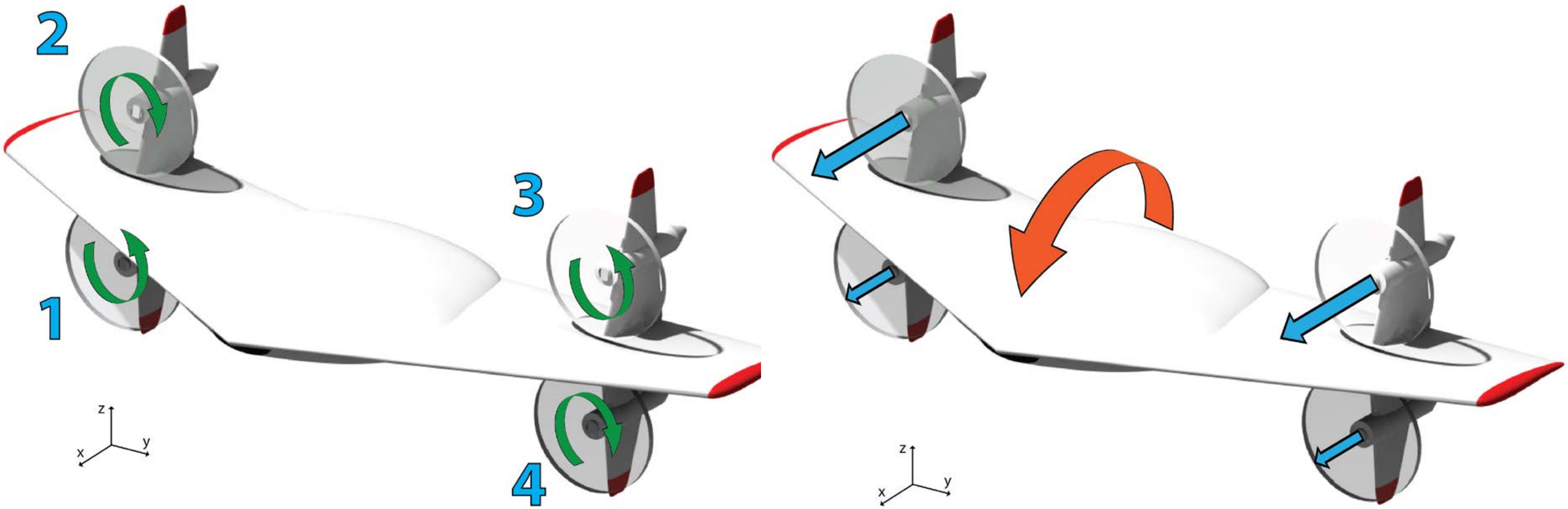
Linearized system

$$\mathbf{x}^{\circ} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$
$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u}$$

$$A = [12x12]$$
$$B = [12x4]$$
$$C = [12x12]I$$
$$D = [12x4][0]$$

Control Design

Pitch control



Control Design

Yaw and roll control check

V $[m/s]$	0				10			
pitch	+	-	-	+	-	+	+	-
roll	-	-	+	+	-	-	+	+
yaw	+	-	+	-	-	-	+	+

Table 11.1: Gains at vertical and horizontal flight

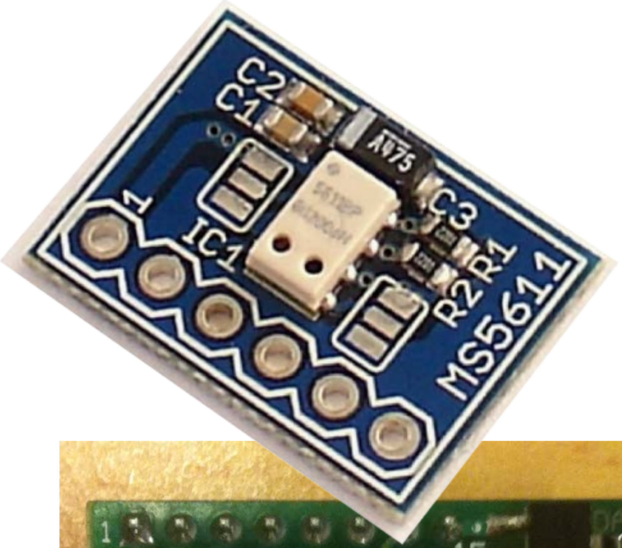
Validation of dynamic model

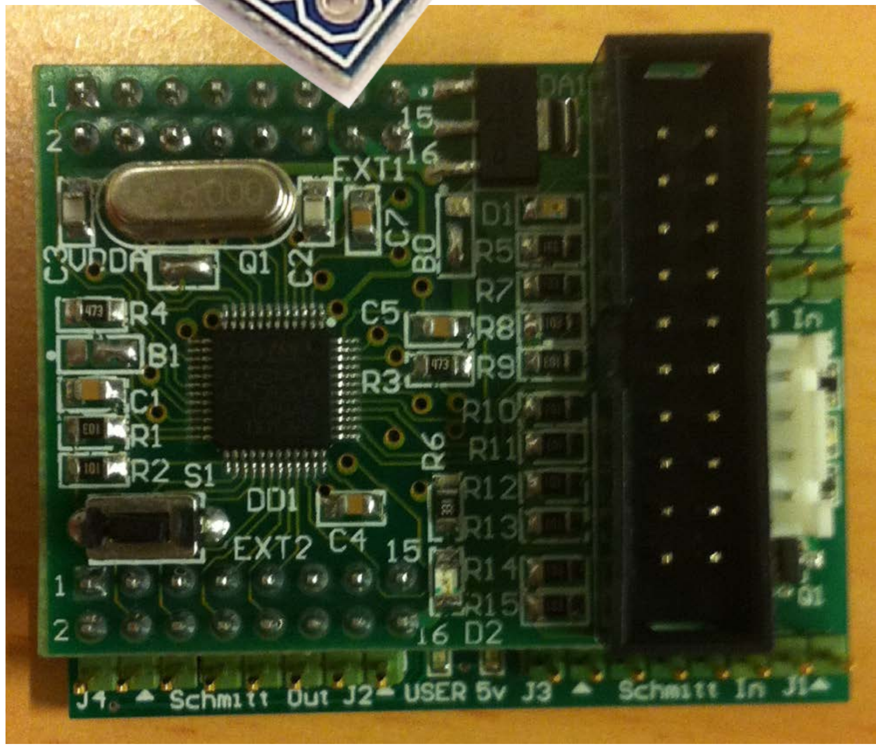
Flight tests

- Accurate flight data
- High frequency (100 Hz)

Log platform:

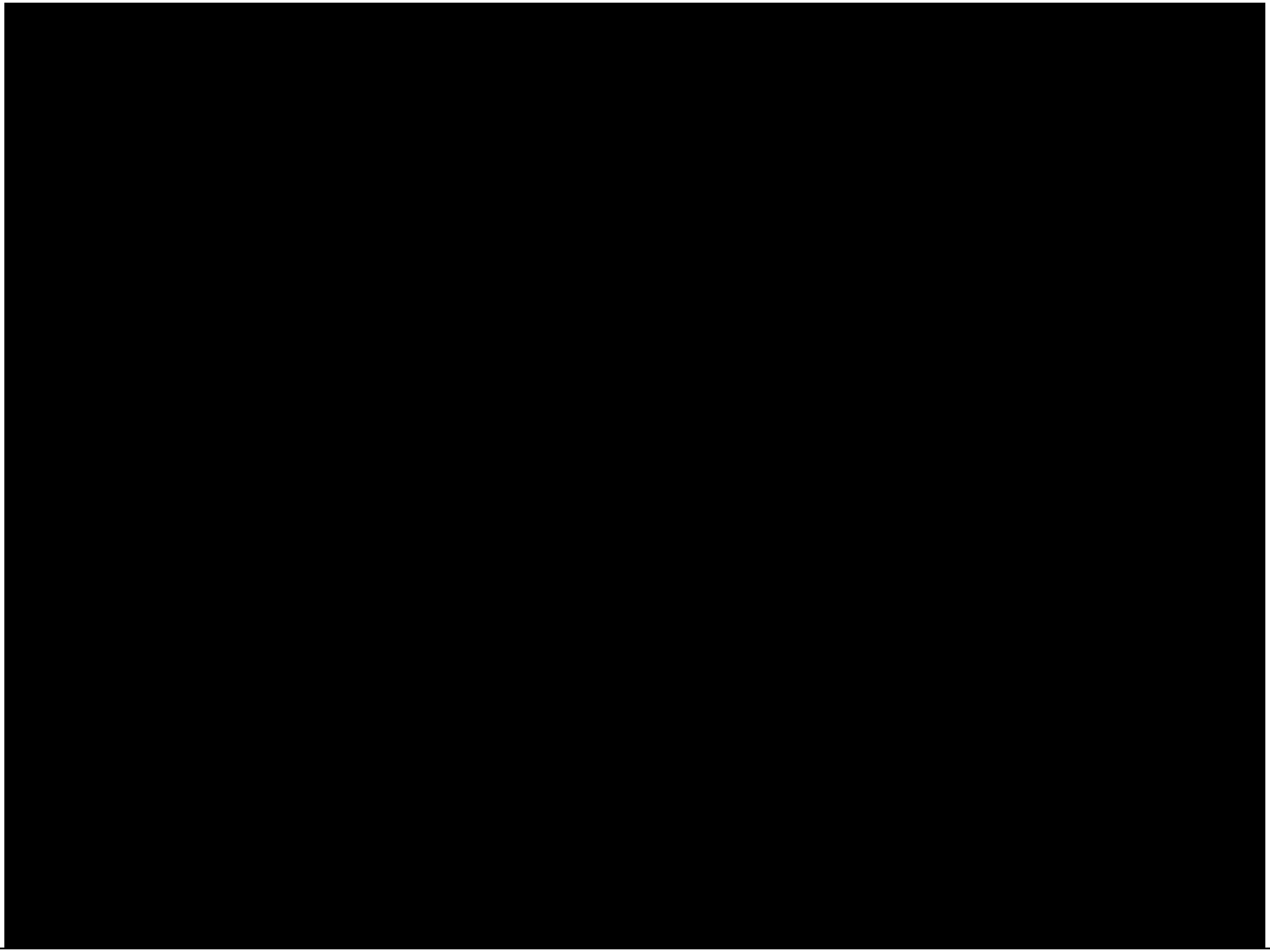
- IMU
- Barometer
- RPM sensors





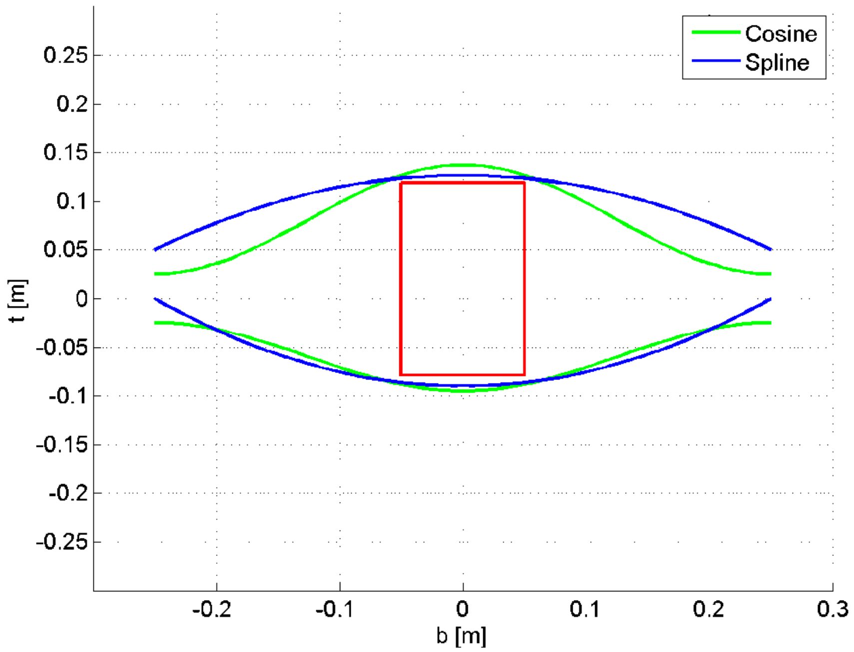
Validation of the log platform

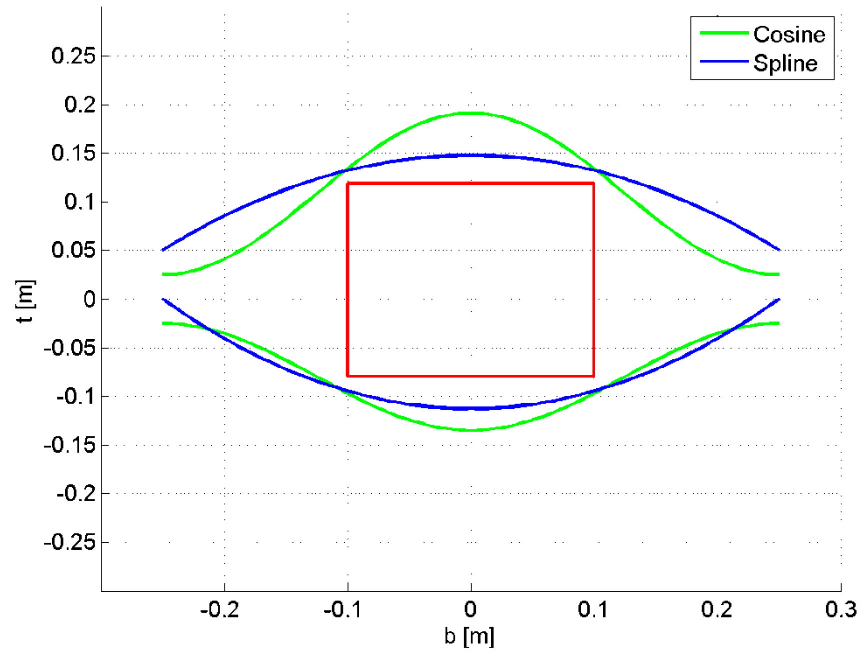
Flight test

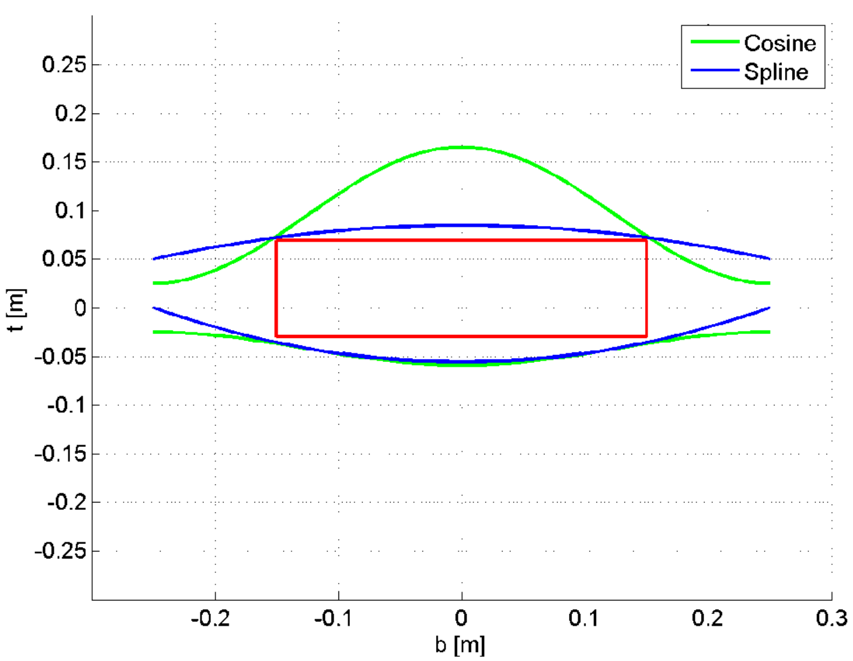


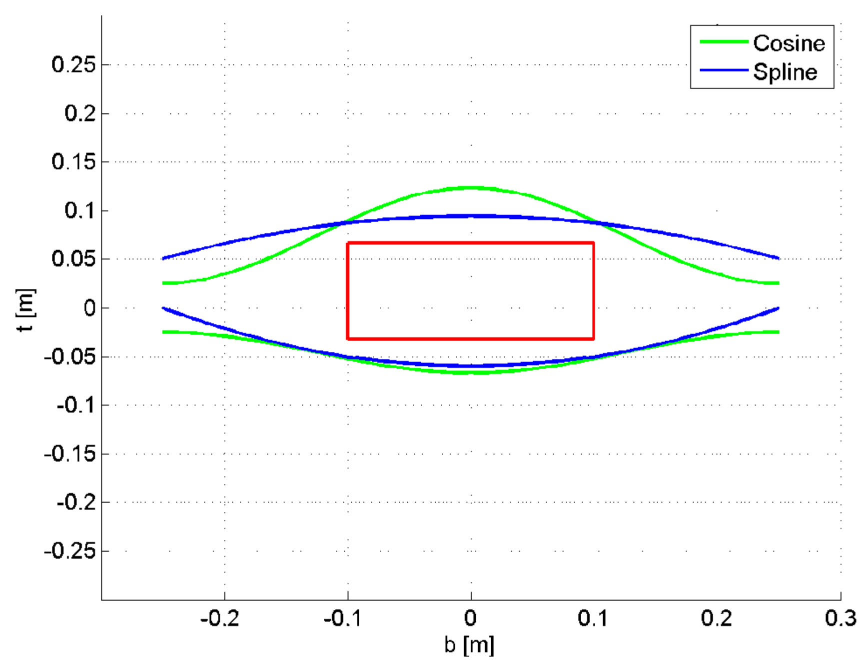
Body sizing

Cosine vs Spline





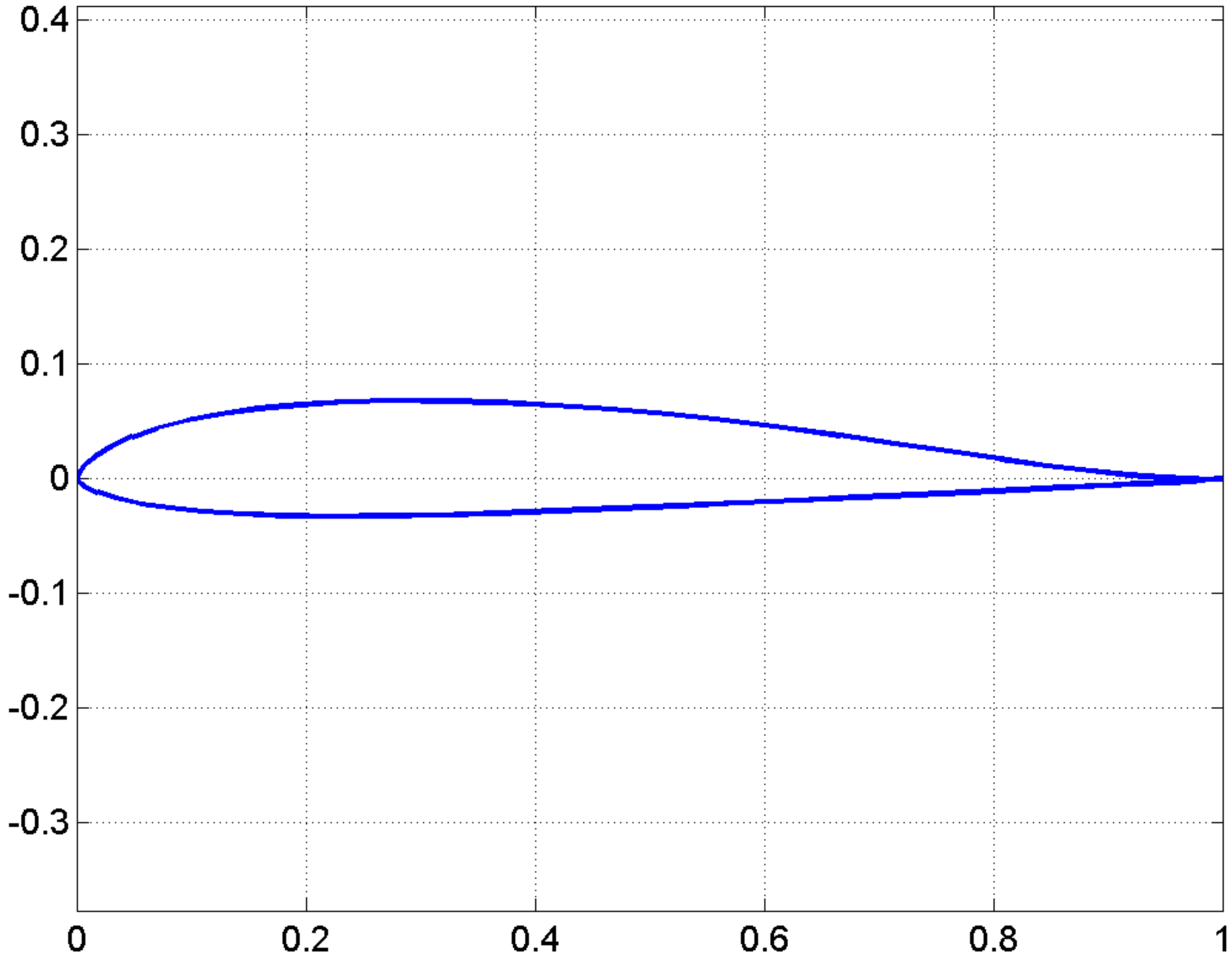




Wing Sizing

Airfoil

MH-60



Tailless aircraft:

- Zero pitch airfoil

Wing Sizing

Lift and drag forces

$$L = \frac{1}{2}\rho V^2 S C_l$$
$$D = \frac{1}{2}\rho V^2 S C_d$$

- C_l = lift coefficient [-]
- C_d = drag coefficient [-]
- V = flight speed [m/s]
- S = wing area [m^2]
- ρ = density of air [$\frac{\mathrm{kg}}{\mathrm{m}^3}$]

Wing sizing

Lift and drag coefficients

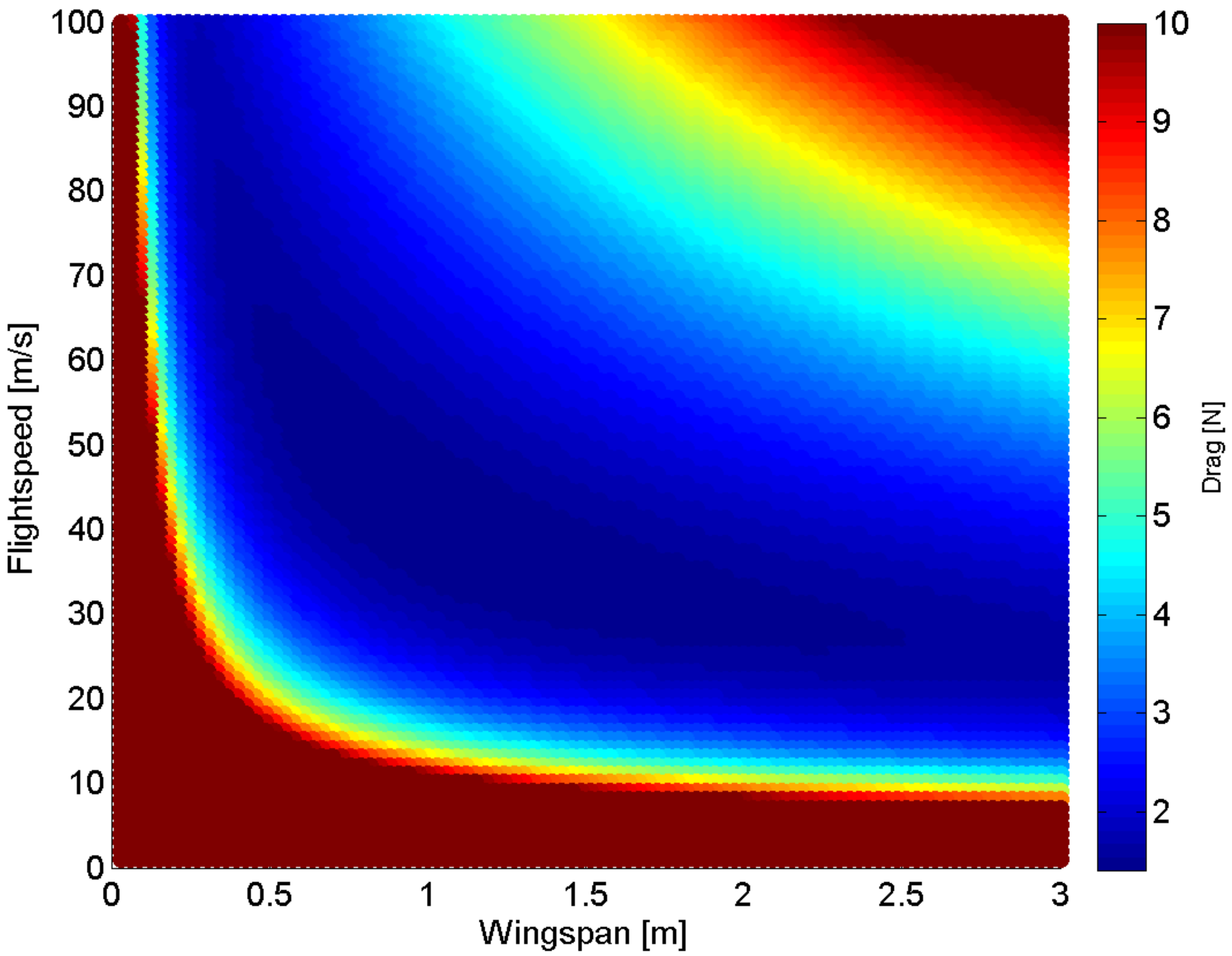
$$C_l = \frac{W}{\frac{1}{2}\rho V^2 A}$$

$$C_d = C_{d_i} + C_{d_p} \qquad C_{d_i} = \frac{C_l^2}{\pi A R e} \qquad C_{d_p} = C_{d_0} + C_{d_1} C_l$$

- AR = aspect ratio [-]
- e = Oswald factor [-]
- π = ratio of circumference of circle to its diameter [-]
- C_{d_0} = zero lift drag coefficient [-]
- C_{d_1} = induced drag coefficient [-]

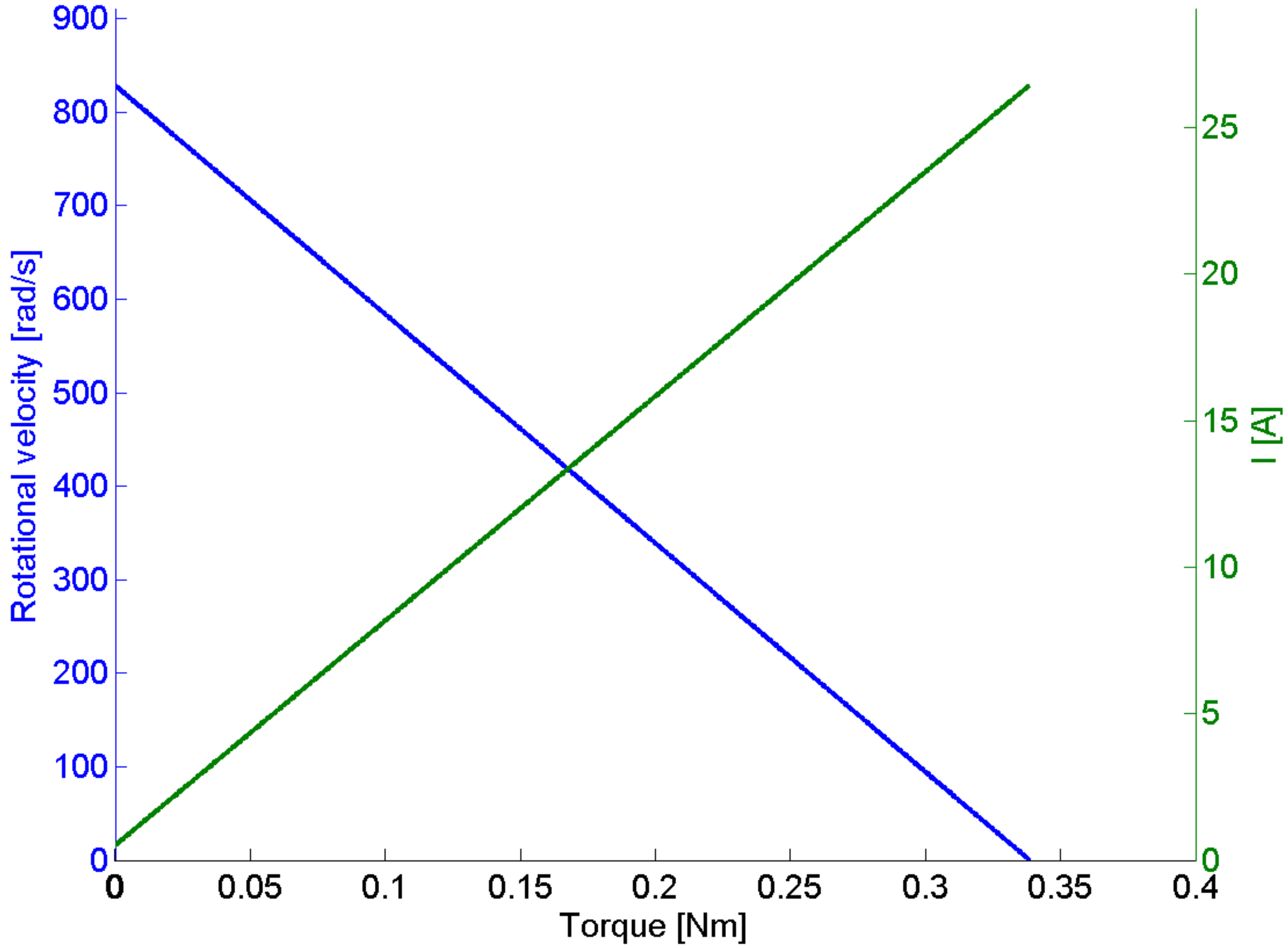
Wing Sizing

Minimum drag



Motor Selection

Motor performance characteristics



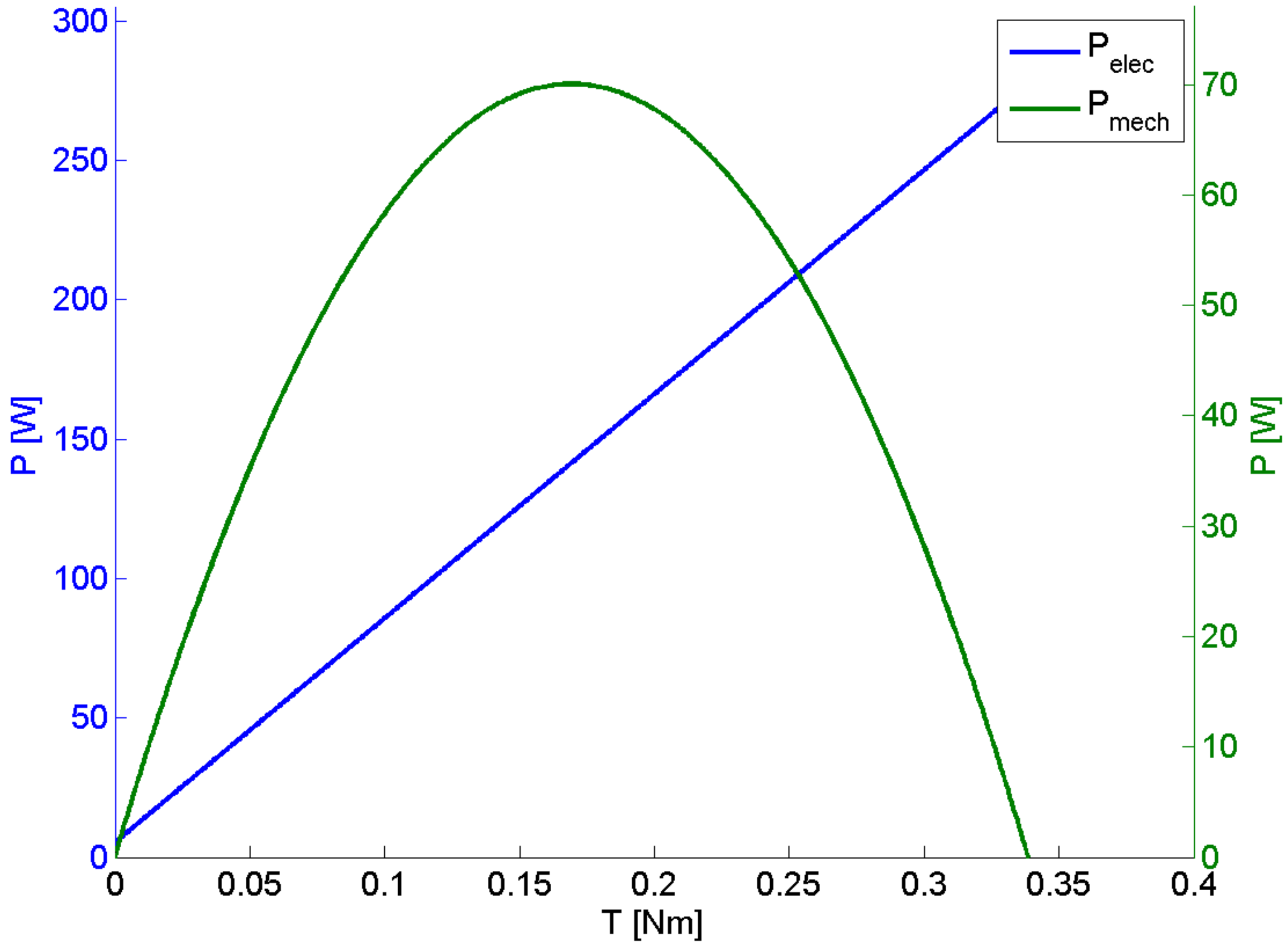
$$Q_m = k_T I$$

$$Q_m = -a_\omega \omega + b_\omega$$

- Q_m = torque [Nm]
- k_T = torque constant [N/A]
- I = current [A]
- ω = rotational velocity [rad/s]

Motor Selection

Motor performance characteristics



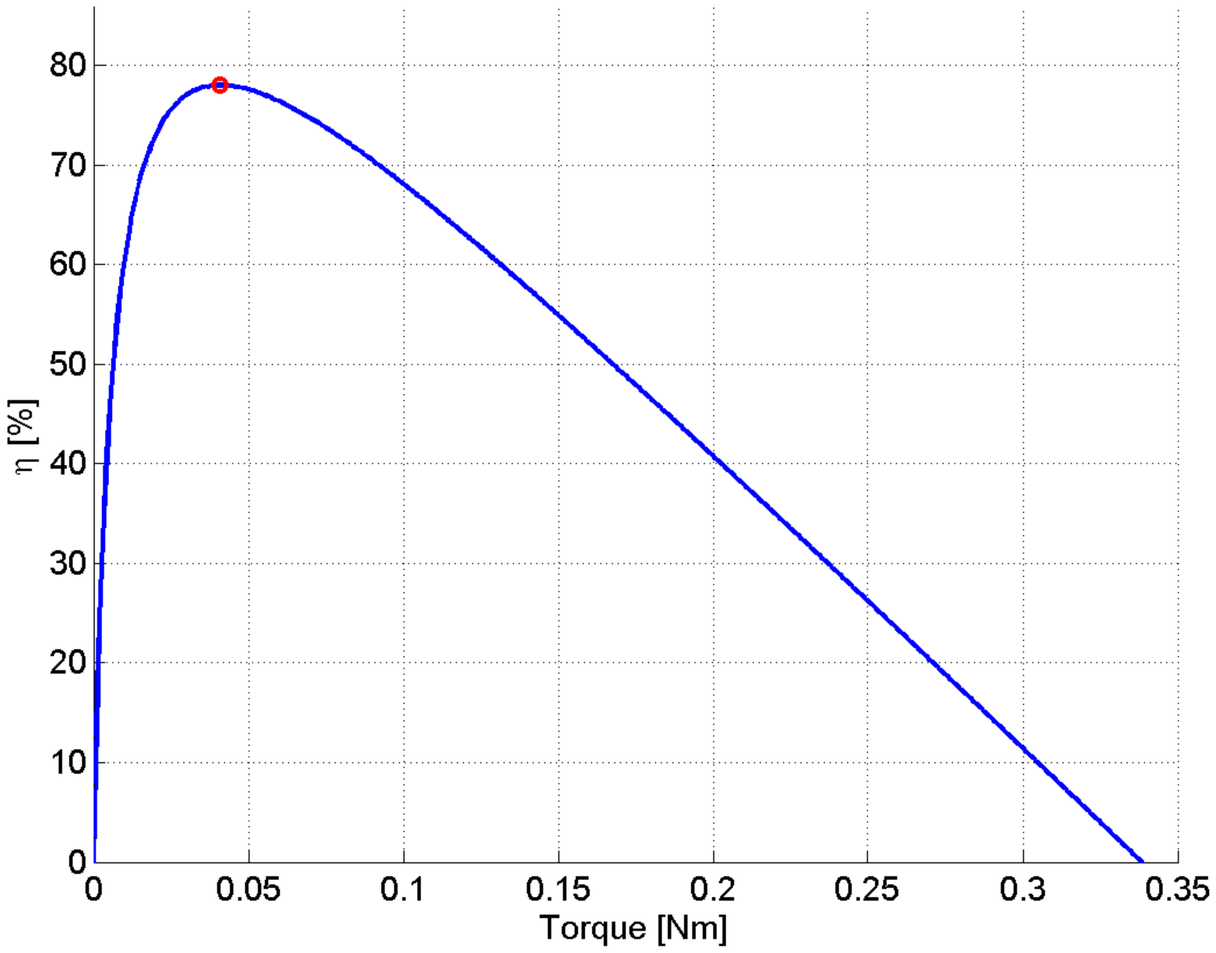
$$P_{elec} = VI$$

$$P_{mech} = \omega Q_m$$

- V = Voltage [V]

Motor Selection

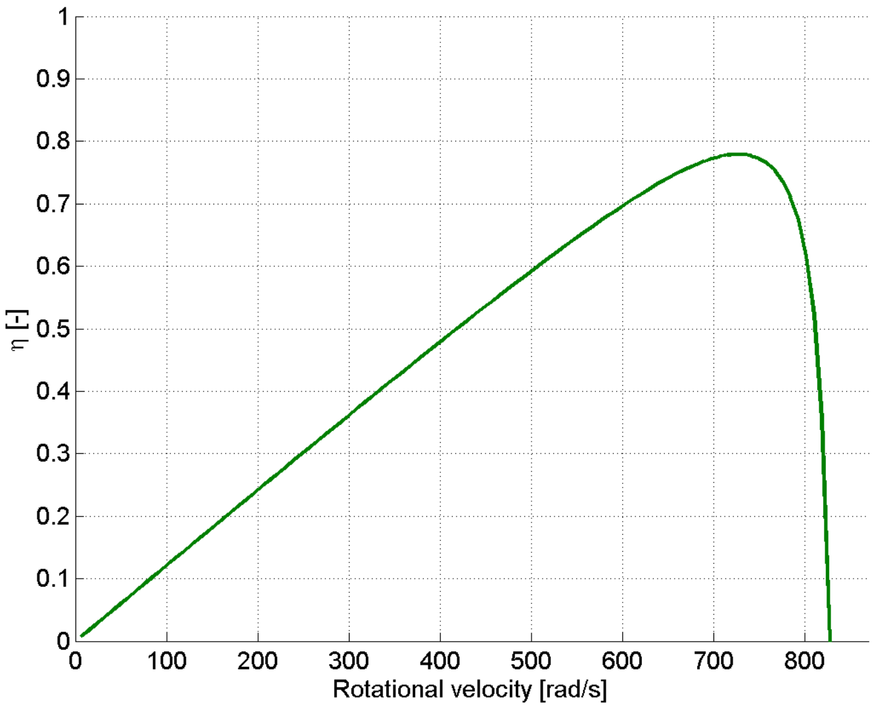
Motor performance characteristics

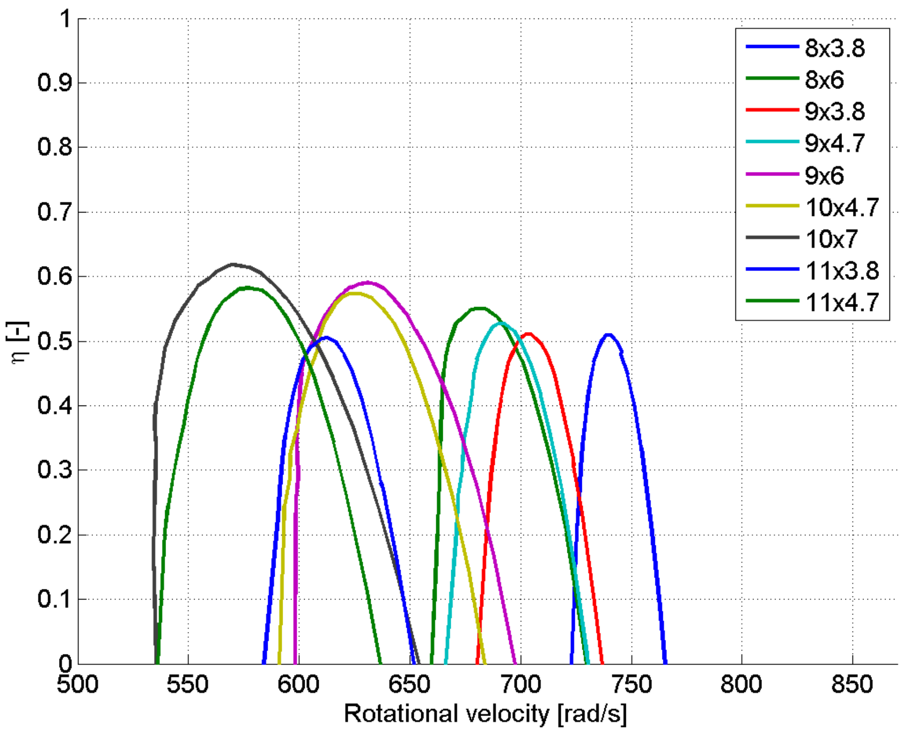


$$\eta = \frac{P_{in}}{P_{out}} = \frac{P_{elec}}{P_{mech}}$$

Total Efficiency Curve(1)

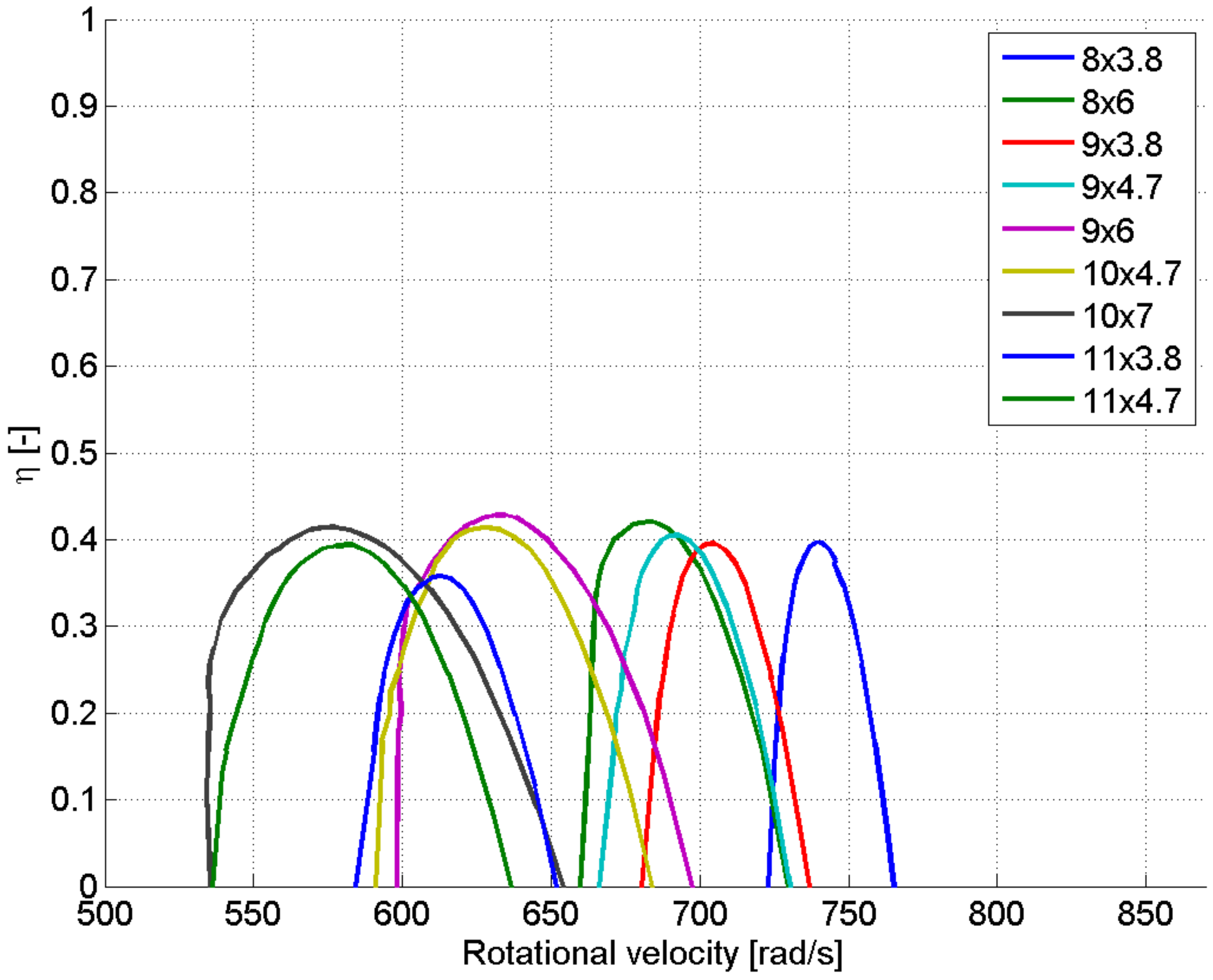
Consistent variables





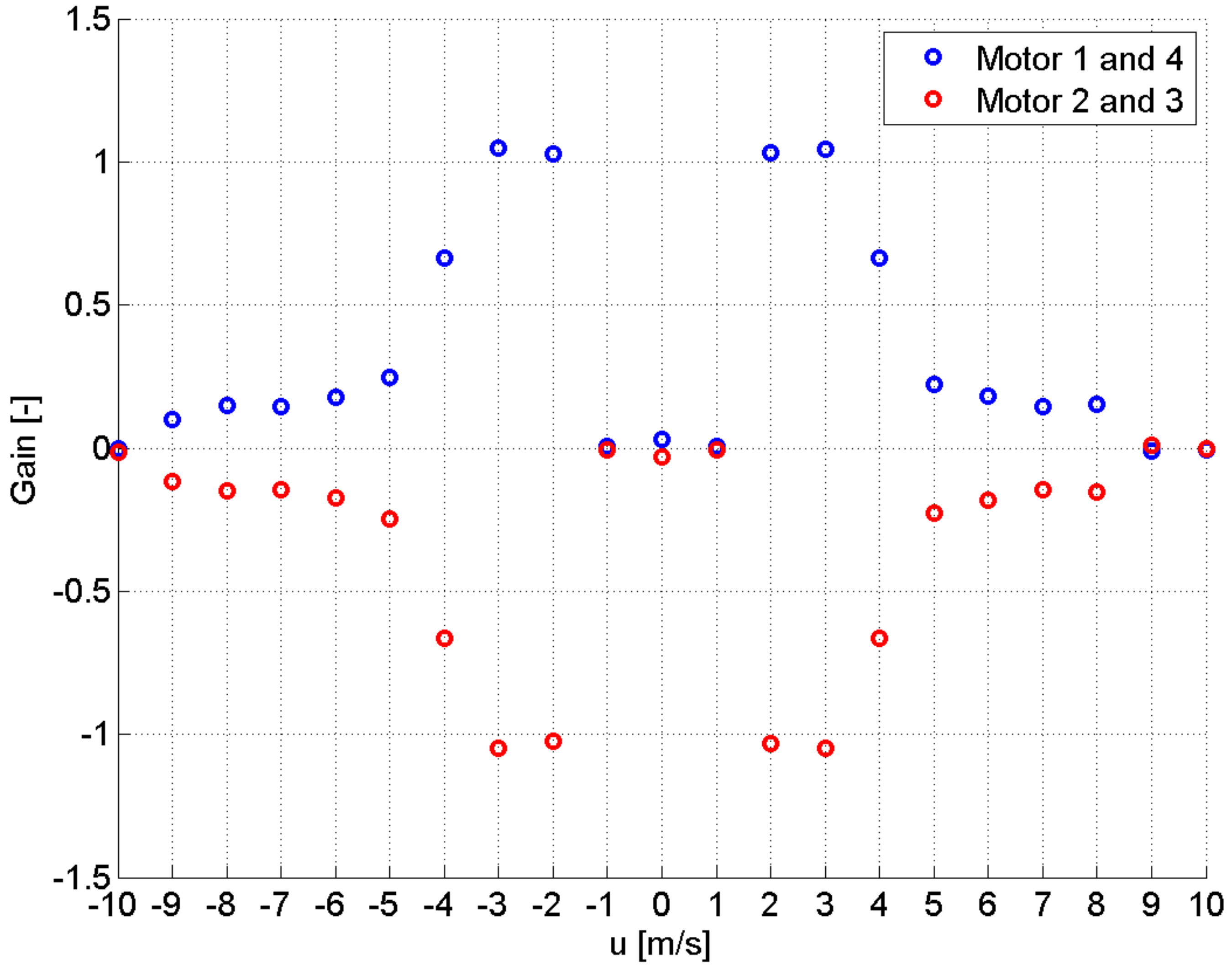
Total Efficiency Curve(1)

Consistent variables



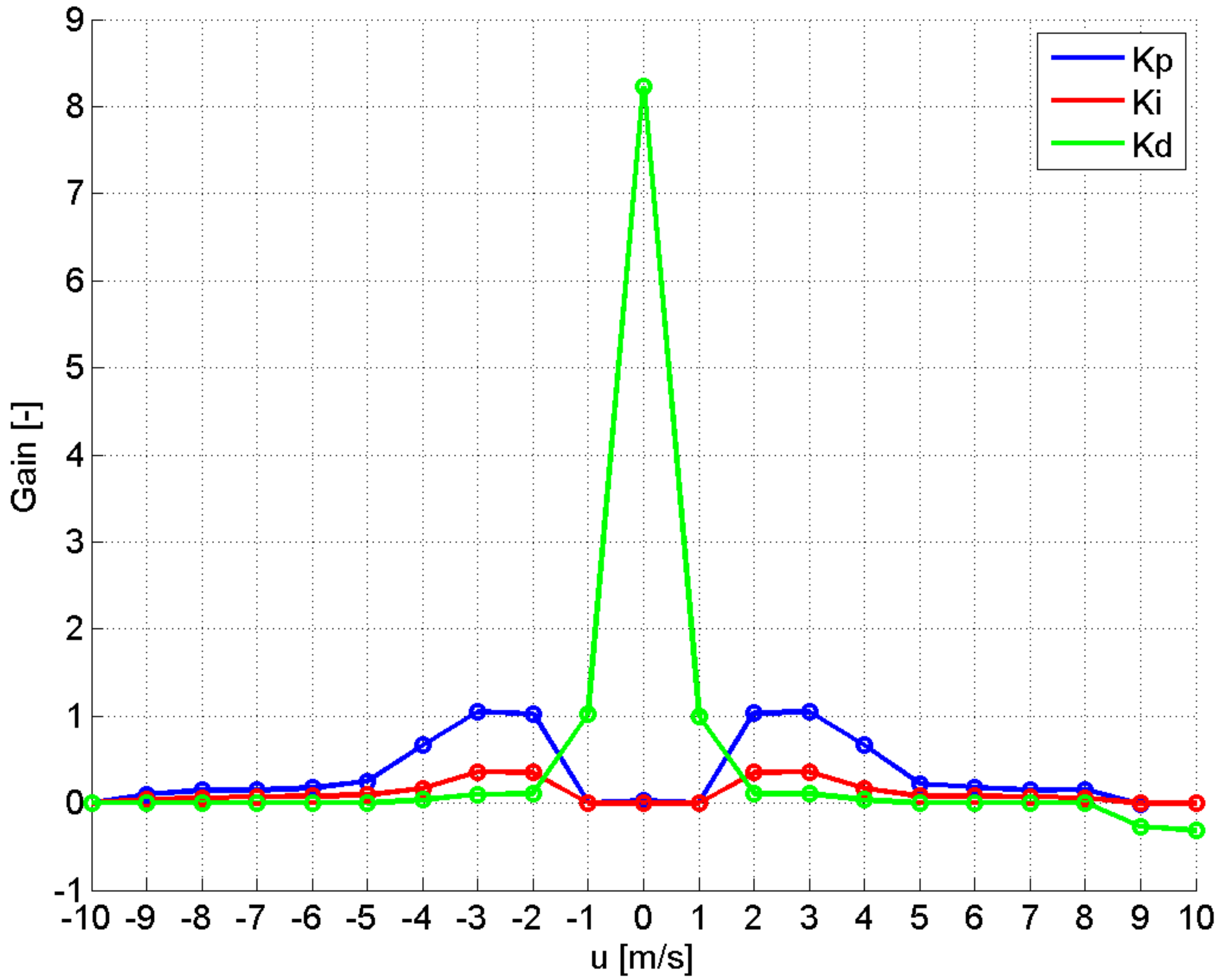
Control Design

Pitch control



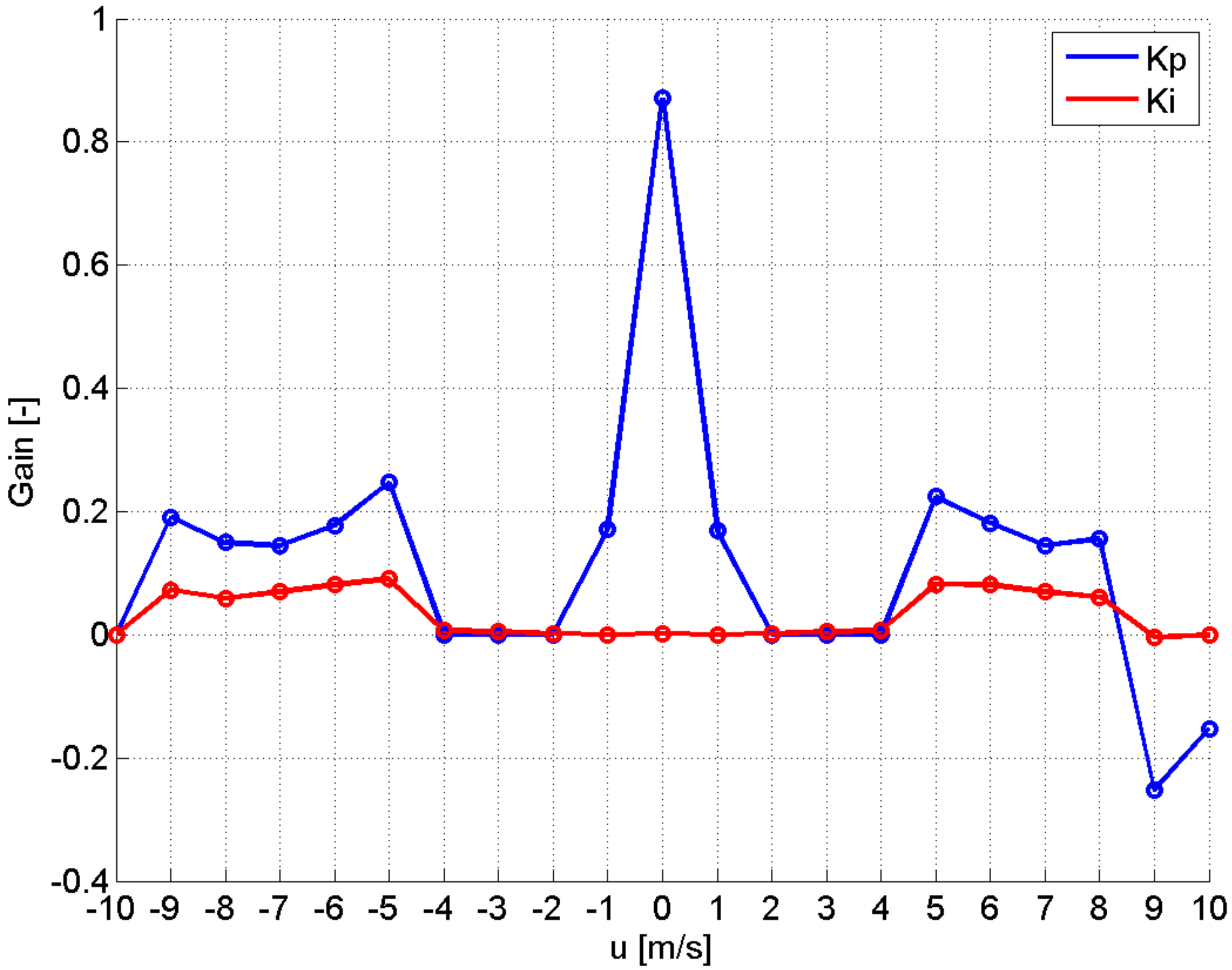
Control Design

Pitch control: Differential gain



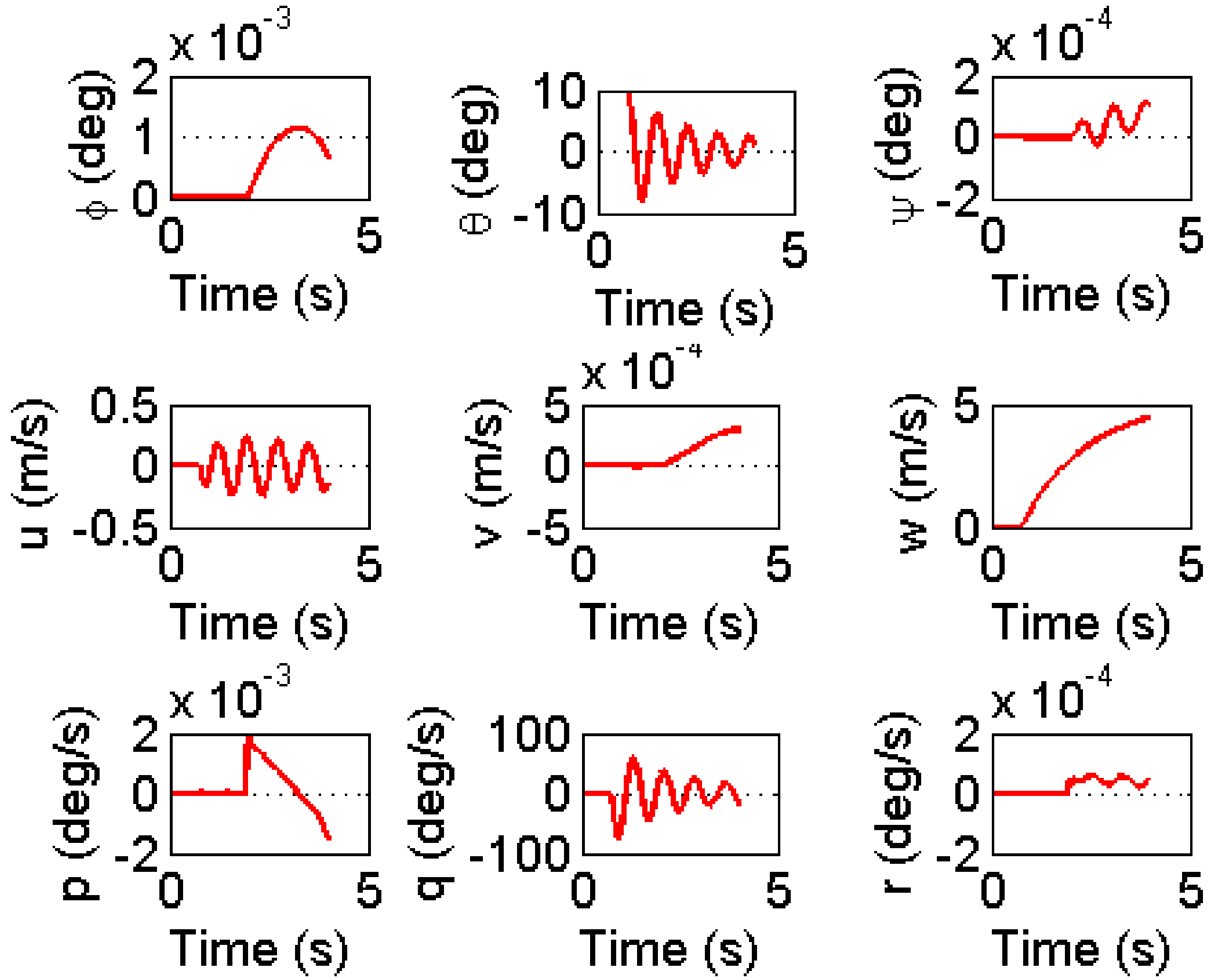
Control Design

Pitch control: PI controller gain scheduling



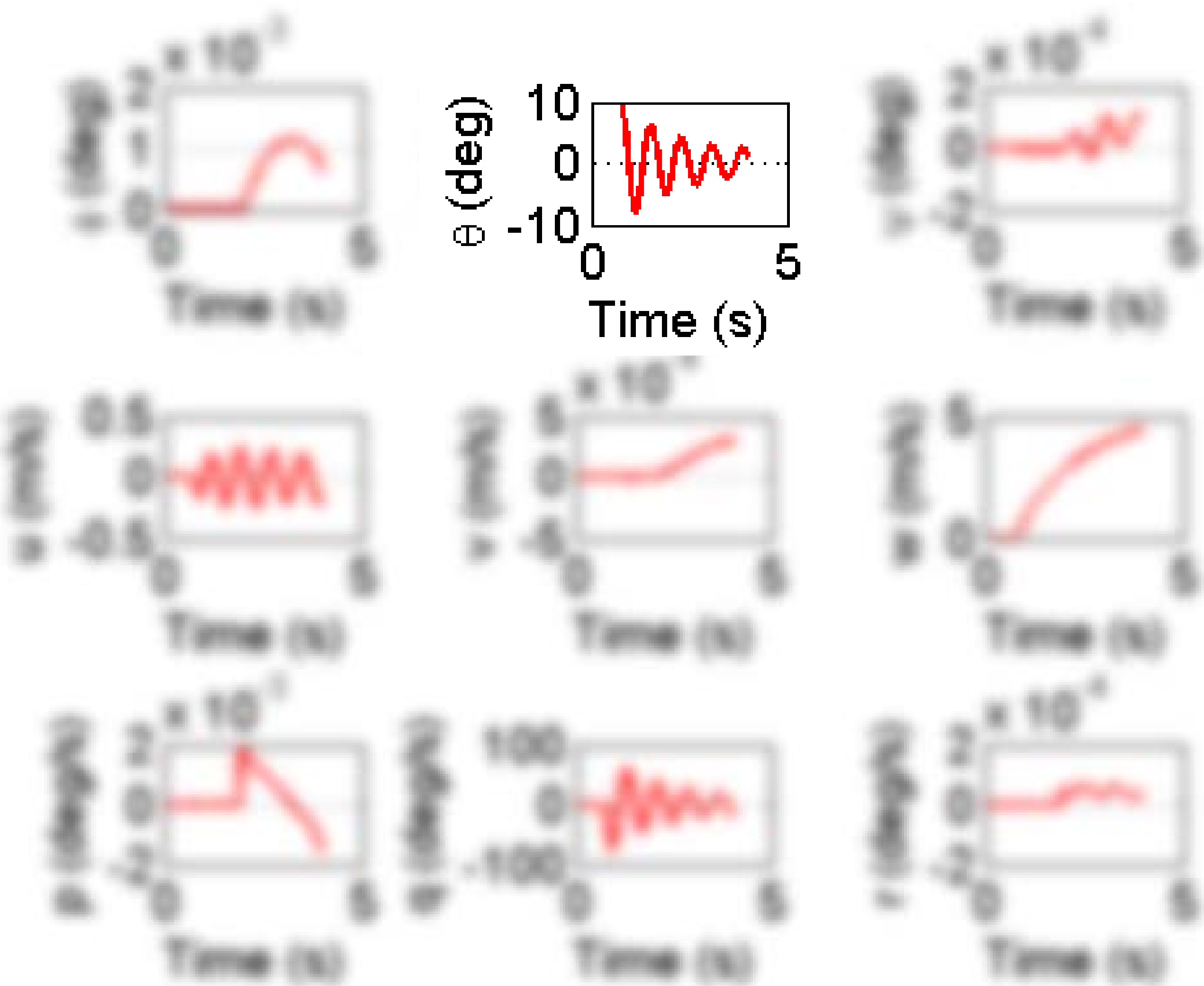
Control Design

Pitch control: simulation



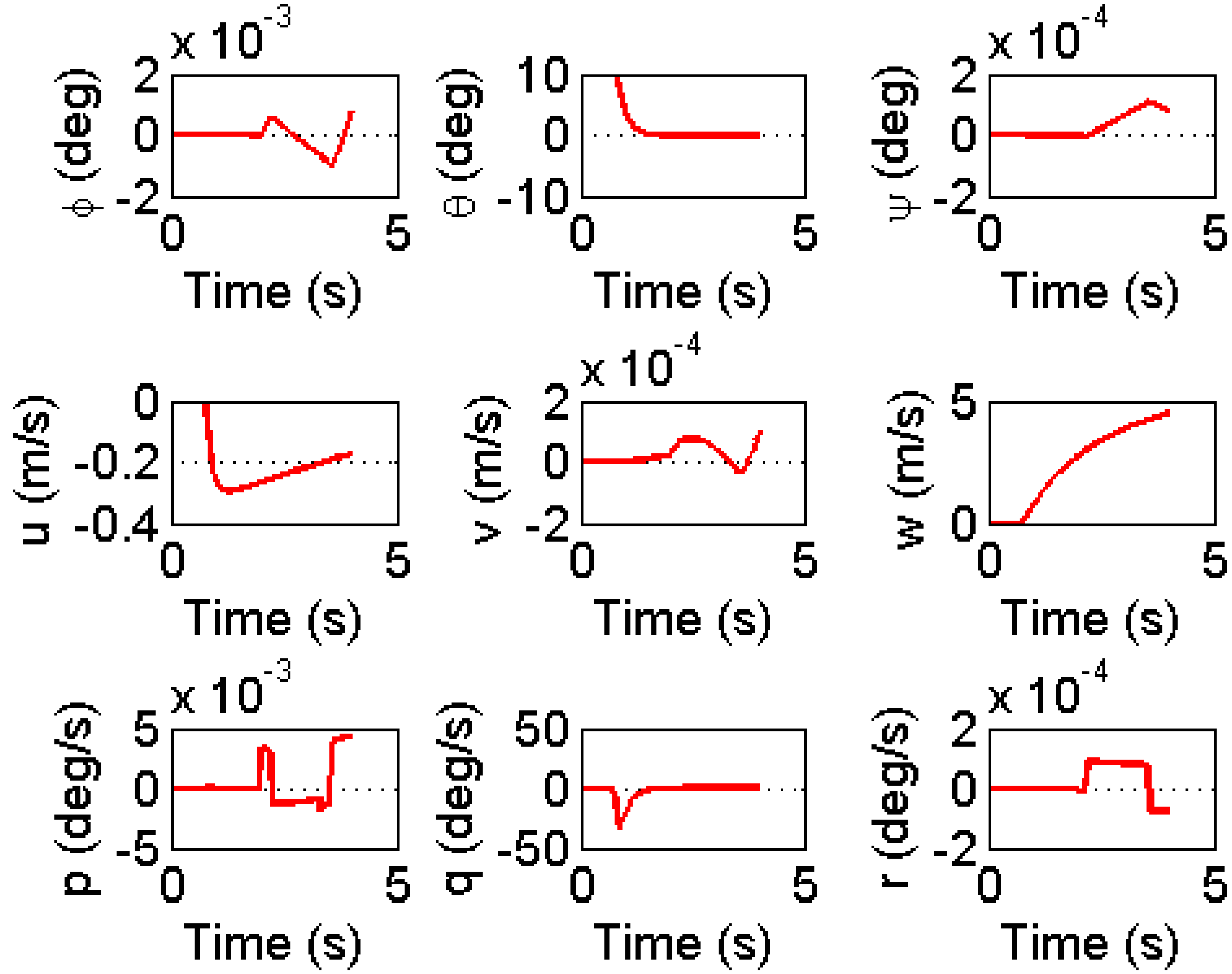
Control Design

Pitch control: simulation PI



Control Design

Pitch control: simulation PID



Validation of dynamic model

Procedure

Cross reference flight data output with model input

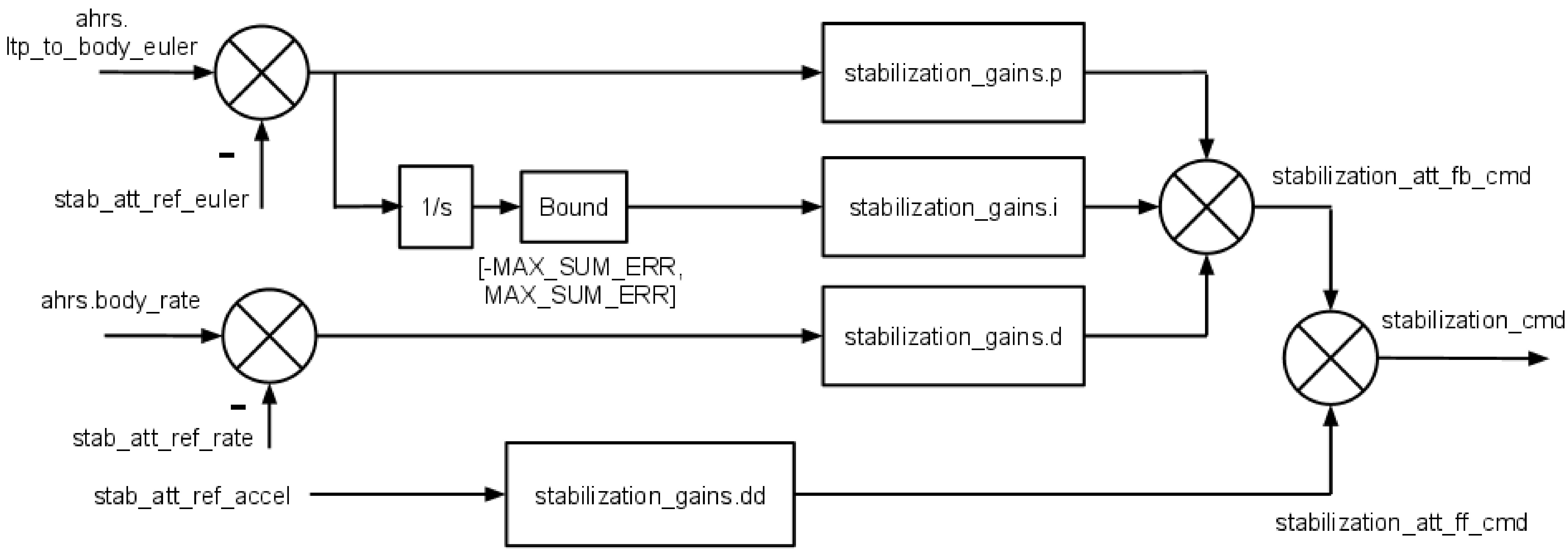
Validation of dynamic model

Flight tests

- Accurate flight data:
  - Attitude
  - Velocities (translational and rotational)
  - Accelerations (translational and rotational)
- High frequency (100 Hz)

A possible control loop

Lisa/M



Dynamic model

Modified model by Skander Tamallaah (NLR)

State vector

$$\mathbf{Y} = \int \dot{\mathbf{Y}} dt$$

$$\mathbf{Y} = \begin{bmatrix} \mathbf{Y_{rb}} \\ \mathbf{Y_{F_i}} \\ \mathbf{Y_{M_i}} \\ \mathbf{Y_{rpm_i}} \\ \mathbf{Y_{V_i}} \end{bmatrix}$$

$$\mathbf{Y_{rb}} = \begin{bmatrix} \mathbf{x} \\ \mathbf{q} \\ \mathbf{v} \\ \omega \end{bmatrix}$$

$$\mathbf{Y_{F_i}} = [F_x F_y F_z]$$

$$\mathbf{Y_{M_i}} = [M_x M_y M_z]$$

Dynamic analysis

Dutch roll

ϕ,β, p and r are coupled

$$\beta = \sin^{-1}\frac{u}{V}$$