AE3212-II

Flight Dynamics Assignment and Flight Briefing

Overview

- Corona protocol
- Registration flow
- Fligt Test logisitcs
- Flight Dynamics assignment
- Short Recap
- Online test

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	AE3212-I	*Flight Test*	*AE3212-II*
Week 3.1	*Lectures*		*Structures assignment*
Week 3.2	*Lectures*		
Week 3.3	*Lectures*		
Week 3.4	*Lectures*	*Test flights*	*Flight Dynamics assignment (incl. synthesis)*
Week 3.5	*Lectures*	*Test flights*	
Week 3.6	*Lectures*	*Test flights*	
Week 3.7	*Lectures*		

Check BrightSpace!

Corona Protocol

Corona protocol approved by

- TU Delft board
- RIVM
- GGD Haaglanden
- Department of Public Health
- Department of Education
- Department of Transport
- Aviation Authorities
- Gemeente Delft
- Gemeente Rotterdam

Corona measures

- Actual Flight is **not** mandatory
- If you want to attend the actual flight, you will have to be PCR tested
- Measures taken to minimize contact and aerosole risk:
  - Always >1,5m distance except 1hr15 in aircraft.
  - PCR test,
  - FFP2 Masks with instructions,
  - Cleaned headsets,
  - Cleaned High visibility jackets,
  - Cleaned aircraft
  - Antisceptic gel in hangar and before entering aircraft

Corona measures

- With all measures taken, there will remain a small nonzero risk

Please evaluate thoroughly and make your own decision to participate

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Admission to the flight test

- Good progress in SVV Structures Assignment, or passed SVV in 2020
- Currently taking AE3212-I FD, or passed FD exam
- Not flown flight test before
- Join the SVV intro lecture on March 1
- Have a valid negative PCR test result
- Pass the online test today

Sign up flow

1. Sign-up for a test flight
2. Schedule a PCR-test at GGD Haaglanden, test location **Delft** or **Rijswijk** within two days of your flight
3. Join the SVV intro lecture on March 1
4. Bring test results to the test flight

Sign up!

- testflight.tudelft.nl
- See also link on BrightSpace
- Open since Tuesday, Feb 23
- SVV-group = flight group

			Escury,F.A.G.	
Tuesday **17/03/2020**	Dekkers,M.G. Kroon,R. Beumer,M.C. Hoogendoorn,H.J. Nagels,T. Keesom,T.B.	van Dalsum,M. Gaffarel,J.Y.P. de Boer,S. Smits,R. van Ede,M.E. El-Kebir,H.	Kanaar,C. Desiderio,M. Campolucci,P. Rodriguez Plaza,E. Trávník,M. Martinez Ruts,M.	Laohamethanee,M.K. Aung Thu Tun, Verkammen,M.H.G. Francotte,T. Kethiri,S.R. Bourgois,J.F.
Wednesday **18/03/2020**	Dijkman,G. Cürgül,Y. Pockelé,J.S. Eftekhar,S. Garcia de Quevedo Suero,B. Riha,B.	Burdo,I.Y. Tunjov,V. van Dalen,S.R. Ummels,R. Vink,T.L.A. Jeon,J.	De hulsters,K. Burr,Z.I. van Veen,A.S.Y. Janssen,I. Tagliacarne,F. van Huffelen,M.C.	Gijsberts,P.R. Sarrazin,N.P.G. de Lange,K.Y.T.Y. Hwang,J. Capus,L. Wen,S.
Thursday **19/03/2020**	Manieri,M. Laar,Y.A. Wegener,M. Sträter,L.P.J. Van Meenen,A.A. Appels,J.P.	Vrouwes,R.M. Middendorp,L.M. Jankowski,M.R. Daugulis,E. Rebosolan,M. Sambath,B.	van Rijthoven,S. Bislip,K.A. Overbosch,E.S.J. Kalsbeek,M.J. Rietveld,M.J. Enting,M.F.G.	Vemulapalli,D. Cacais Pires,D.F. Sakhida,K. Jahjah,N.M. Fazaeli,M.R.B. Hamza,S.M.
Friday **20/03/2020**	3 Tuomaala,A.A.E. Cummins,A.L.G. Floris,M.	Powis,H.M. Sara Boby, Sabino Lopes Vilela Tuna,A. Yoganarasimhan,M.H. Corte Vargas,F. Ramírez Montero,M.	Gonzalez Martinez,P. Silvagni,P. Chatterjee,A. Magri,F. Chung,Y.S. Storme,R.C.G.	1 Dam,F. van Maarschalkerweerd,T.B.G. Schön,P.S. van Deursen,V.D. Steenhuizen,V.C.
Monday **23/03/2020**	Dziarnowska,W. Géczi,M. Origer,S. van Marion,F. Stebbins Dahl,N.P. Jahilo,E.	6		

Flight Schedule

	1st flight	2nd flight	3rd flight	4th flight
mandatory report and check in by telephone or in person at Rotterdam airport Poort 19 (Fairoaksbaan 50) Information about the go or no go of the flight can only be obtained at **06-21203049**	Report 08.00-08.15 in person	Report 09.45-10.00 in person	Report 09.30-10.00 by telephone Check in at 12.15	Report 09.30-10.00 by telephone Check in at 14.00
Rotterdam Airport Poort 19 (Fairoaksbaan 50) **check in closed**	08.30	10.30	12.45	14.30
Start briefing	08.45	10.30	13.00	14.45
Test flight	09.30 – 10.45	11.15 – 12.30	13.45 – 15.00	15.30 – 16.45

TUDelft

BRING YOUR PASSPORT !

Trouble registering for a flight

Unable to sign in

- Email Wouter van der Wal: W.vanderWal@tudelft.nl
  he will check what the problem is and add you to the list

Can't / don't want to fly

- Email Wouter van der Wal: W.vanderWal@tudelft.nl
  you will be added to a SVV group

You did SVV in 2020, but could not fly due to CoVid

- You will be able to sign up in the second week of March.
  More info to follow on BrightSpace

Schedule PCR test

Test result is valid 48 hours → So schedule test 1 to 2 days before your flight

1. Try to schedule via coronatest.nl

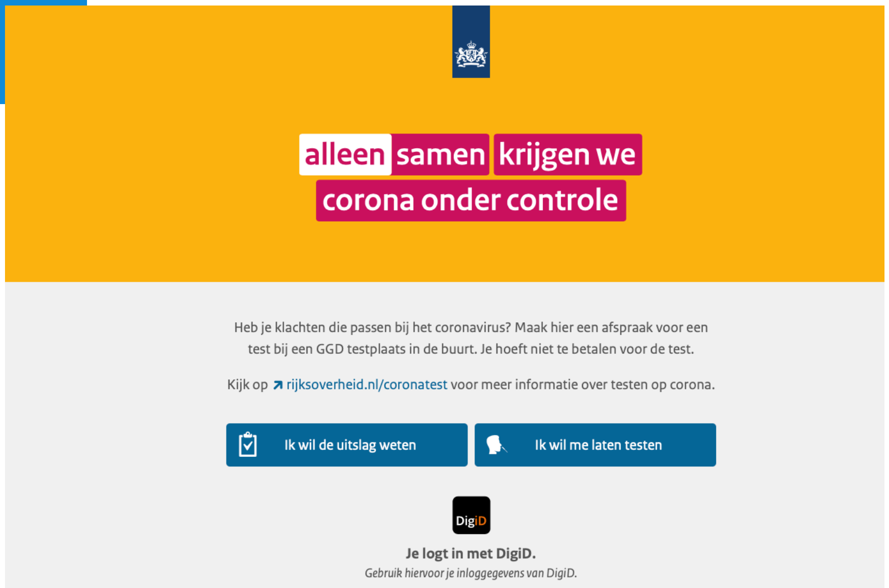
2. **IF** no suitable date can be found on the website: call **0800-1202**

3. **IF** the telephone operator is unaware of the TU Delft practical and does not want to schedule the PCR test:

   Call **088-35 50 100** and follow the menu:

   0: CORONA
   3: aanvragen test (schedule test)
   3: overige vragen --> expertise centrum corona (other questions --> expertise center corona)

Schedule your PCR + quicktest



1. Go to coronatest.nl
2. Requires DigiD!
3. Answer all the questions truthfully
4. Schedule a PCR-test at GGD Haaglanden location Delft or Rijswijk, within two days before your flight
5. Bring the TU Delft declaration form to the test (available on Brightspace)

PCR test: required for test flight
Quick test: on request of GGD for research

When should I do the test?

Test on	*Fly on*
Sunday	Monday or Tuesday
Monday	Tuesday or Wednesday
Tuesday	Wednesday or Thursday
Wednesday	Thursday or Friday

Test results are valid for a maximum of 48 hours!

What if I don’t want to fly

1. No problem! Flight is NOT mandatory
2. Email Wouter van der Wal: W.vanderWal@tudelft.nl
3. You will be added to a SVV group

What if I am sick on the day of my flight or have been in contact with someone who has Corona

1. **DO NOT COME TO THE AIRPORT!**
2. Email Wouter van der Wal: W.vanderWal@tudelft.nl
3. When you are better, you can schedule a new PCR test after 5 days
4. Plan a later flight
5. No flights left? You get to fly next year

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BRING YOUR PASSPORT !

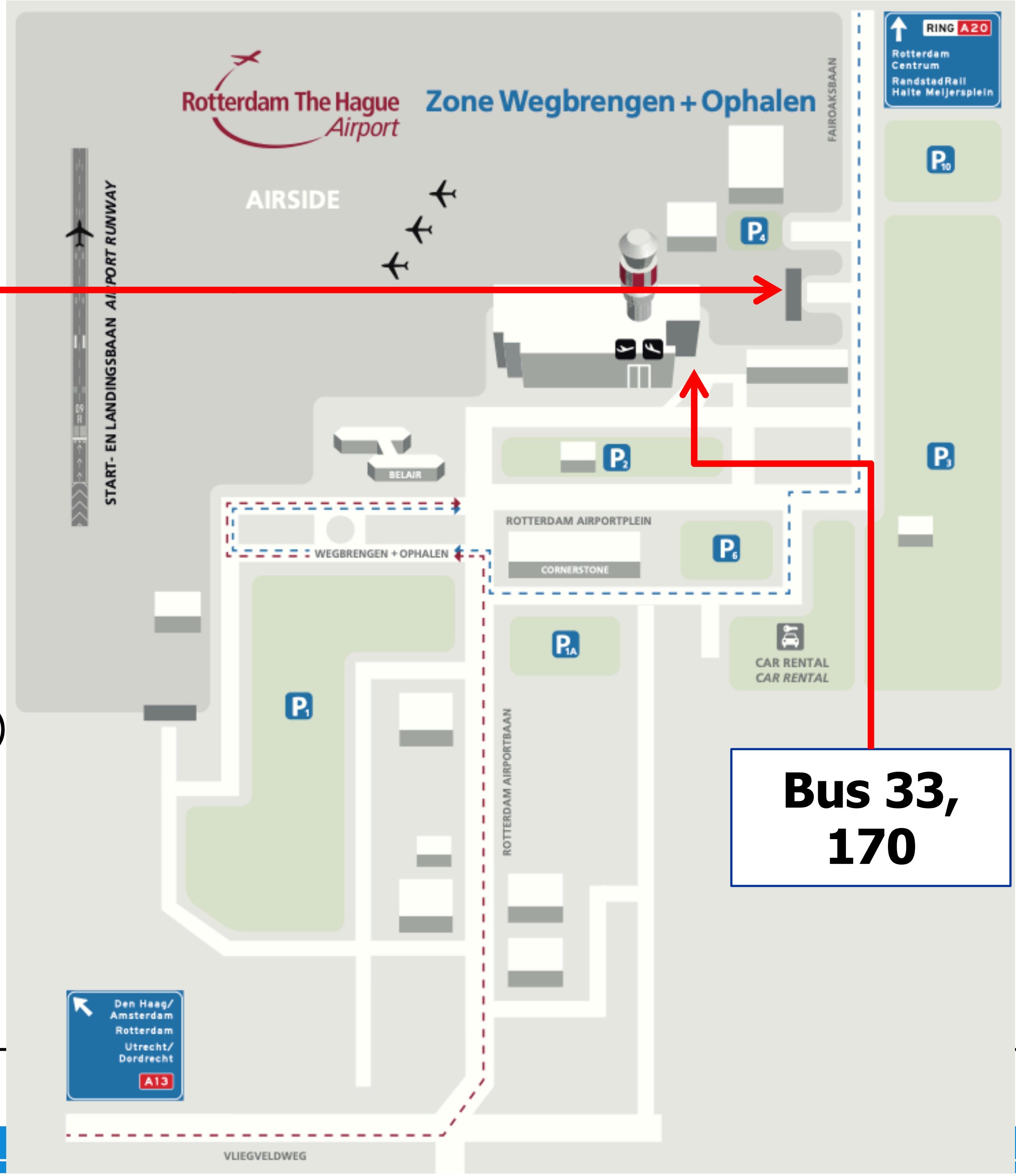
Report at Rotterdam Airport – Gate 19

Poort 19

- Use the following addres:

Fairoaksbaan 50

- You can park your bike at Gate 19
- Bus 33 or 170 to Rotterdam Airport (600 m walk)
- **No car park** at Gate 19
- P1, P2, P6 paid parking (10 min walk), P10 **not** available



General behaviour

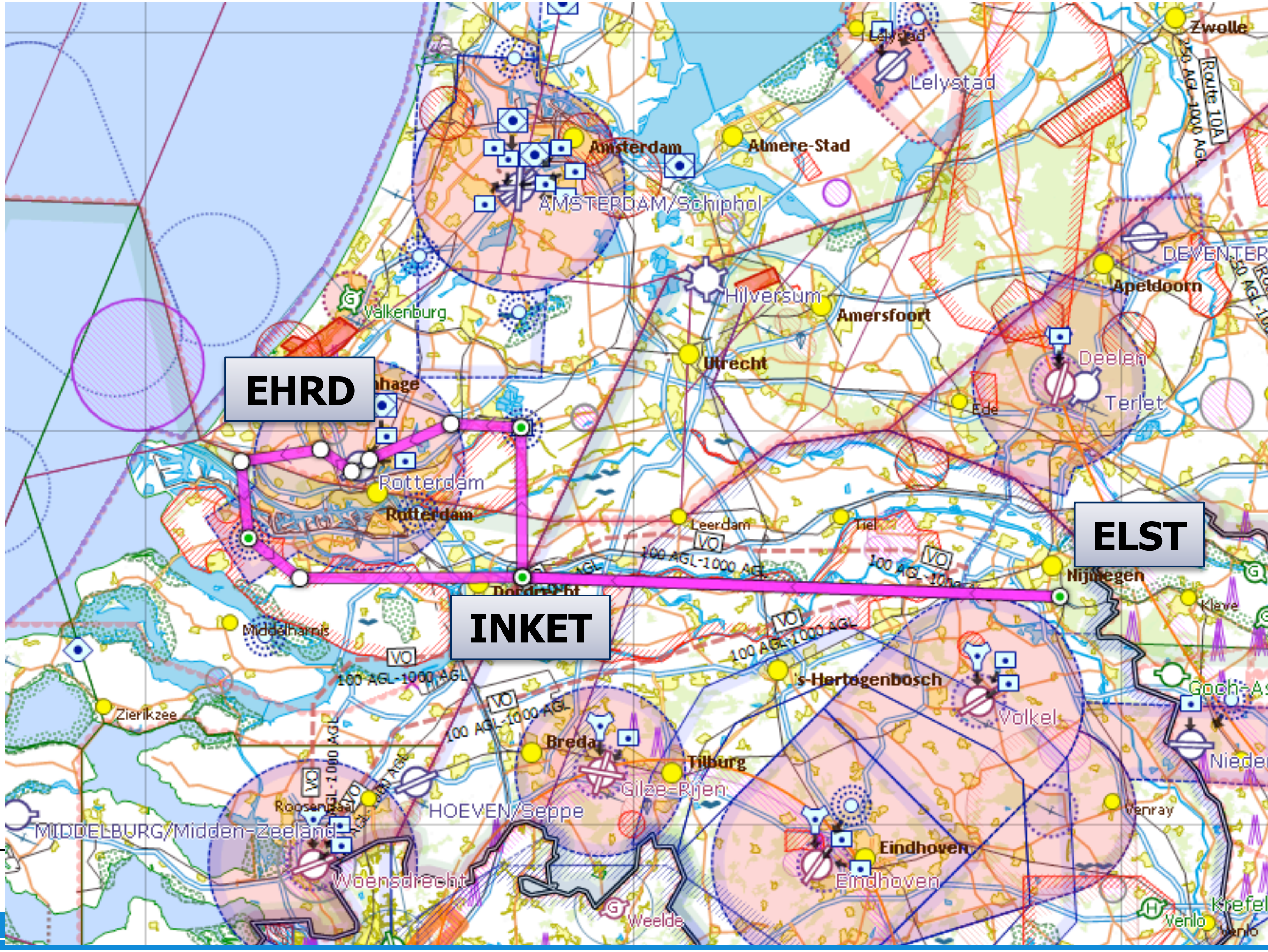
- Always keep >1.5 m distance, make it more when possible
- Only place where <1.5m is inside the aircraft
- Wear a face mask
- Do not help other students by touching them or hold something for them (also no phone for picture)

Consent form

- To be filled out in the hangar before the flight
- You consent that the flight is voluntary and that you participate out of your own free will
- You consent that the risk to catch Covid 19 is not zero

Cameras in the hangar

- There are camera’s placed in the hangar
- Only to see movements, no pictures are made
- See https://youtu.be/VL5xGeCVAOs


EHRD
INKET
ELST
Amsterdam
AMSTERDAM/Schiphol
Almere-Stad
Lelystad
Zwolle
DEVENTER
Apeldoorn
Hilversum
Amersfoort
Utrecht
Deelen
Terlet
Ede
Valkenburg
Rotterdam
Leerdam
Tiel
Nijmegen
Kleve
Dordrecht
Middelharnis
Zierikzee
's-Hertogenbosch
Volkel
Breda
Tilburg
Gilze-Rijen
HOEVEN/Seppe
Roosendaal
MIDDELBURG/Midden-Zeeland
Woensdrecht
Eindhoven
Weelde
Venray
Venlo
100 AGL-1000 AGL

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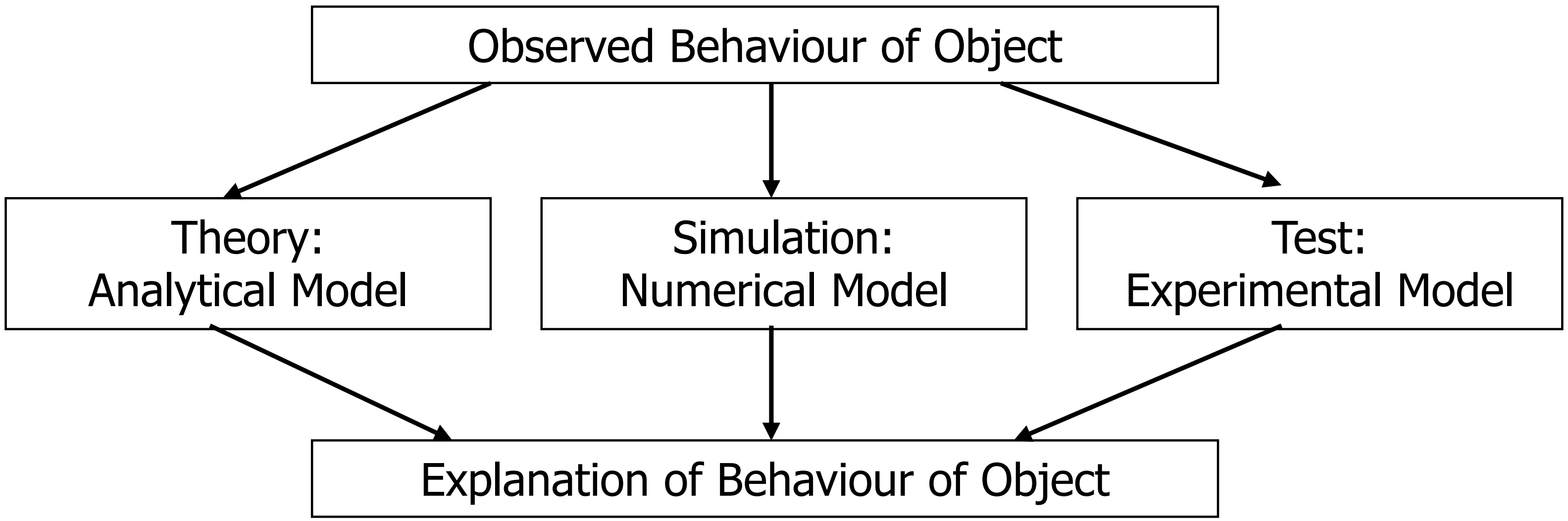
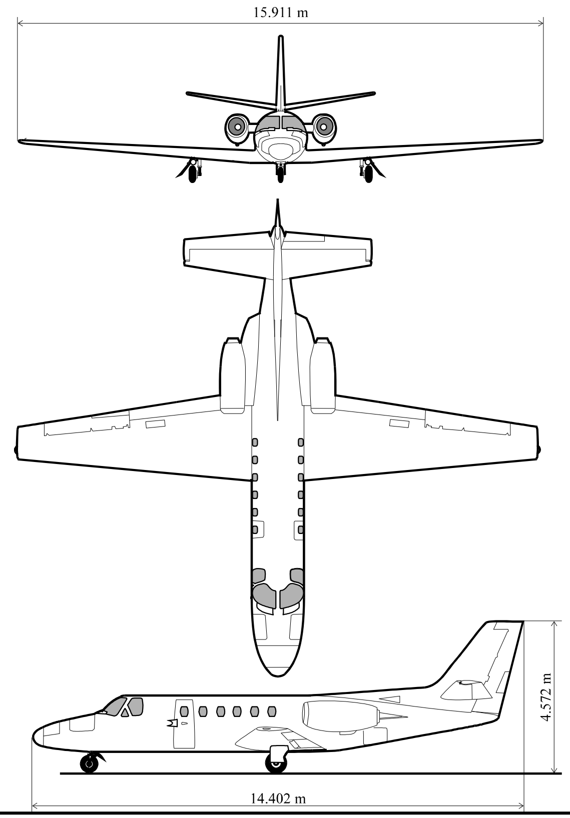
Simulation, Verification and Validation

Theoretical analysis, computer simulation and measuring or testing are used to evaluate, verify and validate observed performance or failure of aerospace vehicles and phenomena

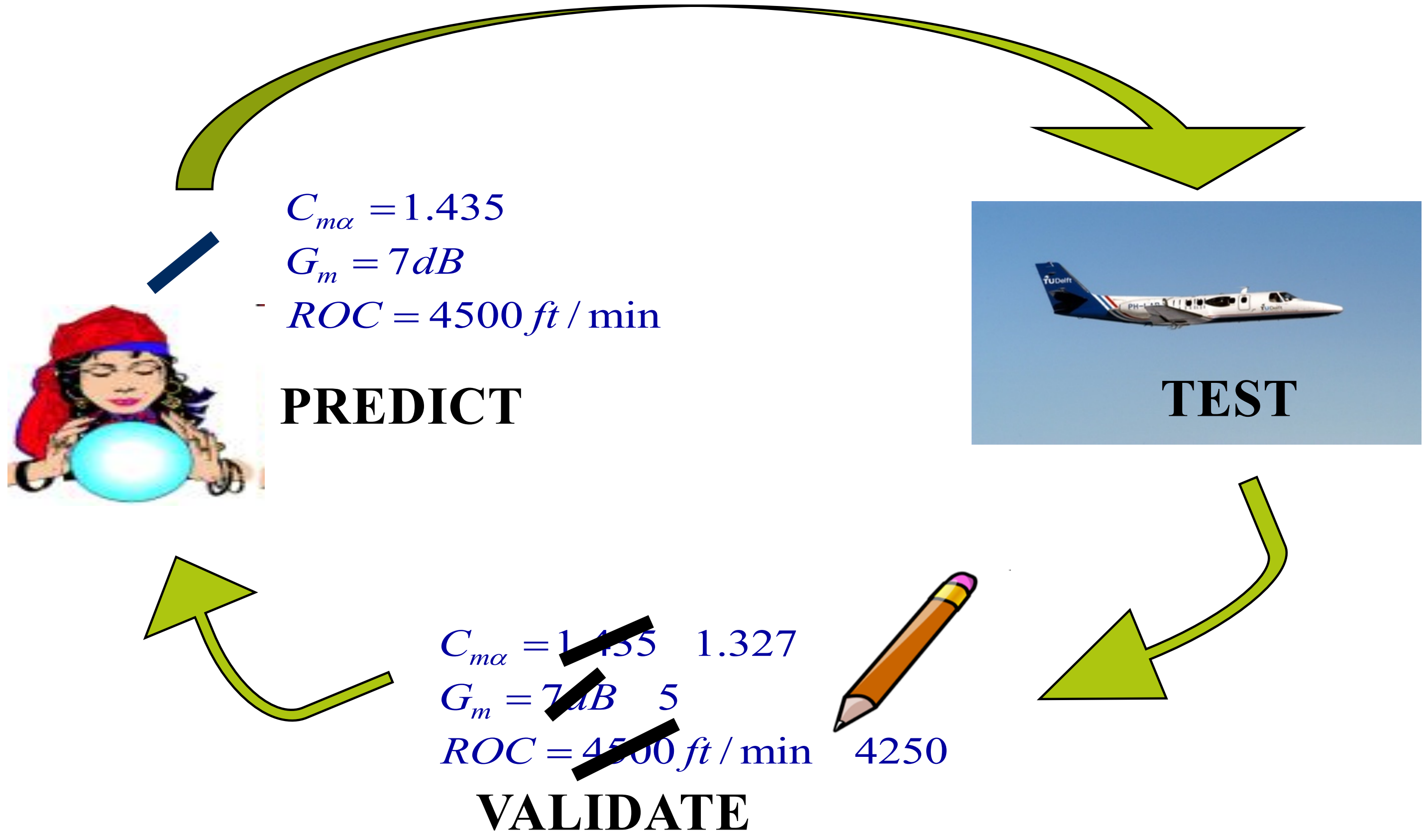


AE3212-II Flight Dynamics Assignment

- New aircraft design
- Limited data available
- Predict dynamic behavior
- Adjust design to improve behavior



Model development



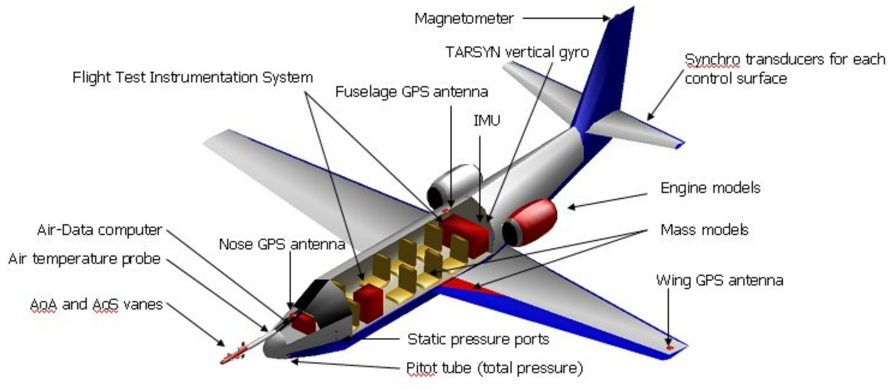
Model validation test method

- Build a mathematical model
- Predict performance and behavior
- Test the model
- Adjust the mathematical model

Flight Simulation purposes

- Fly before you build
- Testing dangerous conditions
- Training simulators
- Future modifications

Flight Test Data



<u>Stationary measurements series 1</u>

- To determine a number of aerodynamic coefficients

<u>Stationary measurements series 2</u>

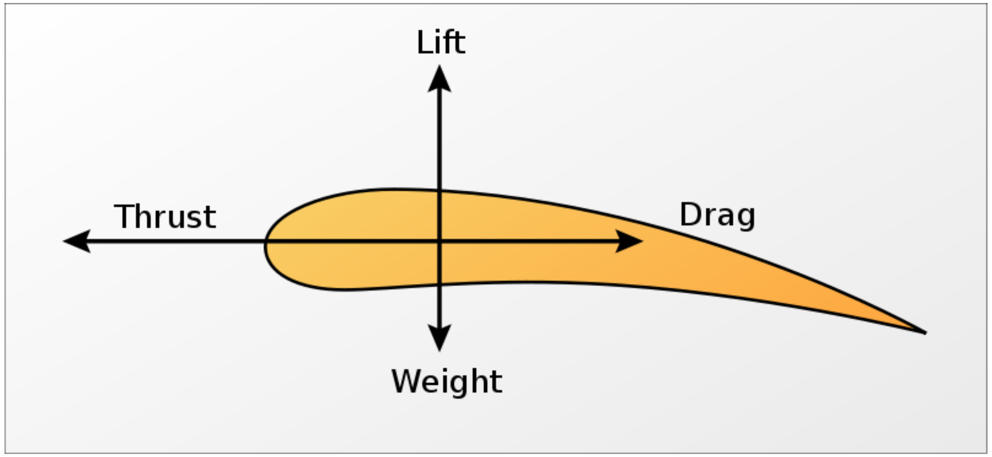
- To determine a number of stability derivatives
- To determine longitudinal stability

<u>Dynamic measurements</u>

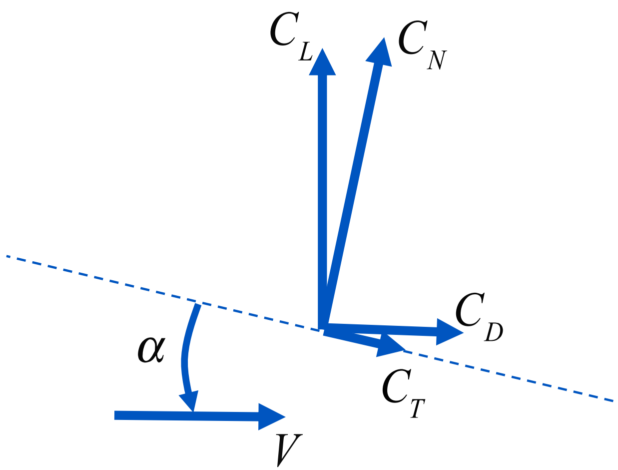
- To determine Eigenmotion characteristics
- To validate simulation results

First measurement series

- Steady, horizontal flight
- Constant altitude, varying thrust
- Data for speedrange $V_S \rightarrow V_{MO}$
- One configuration:
  - Gear up, flaps up



Aerodynamic coefficients

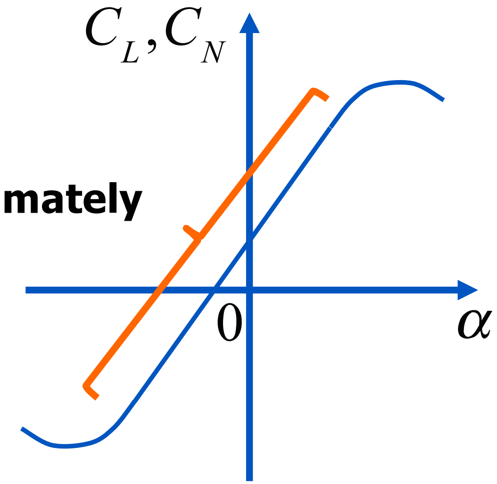


Steady, horizontal flight

Vertical equilibrium:

$$C_L = \frac{W}{\frac{1}{2}\rho V^2 S} = C_{L_\alpha}(\alpha - \alpha_0) \approx C_{N_\alpha}(\alpha - \alpha_0)$$

Approximately linear

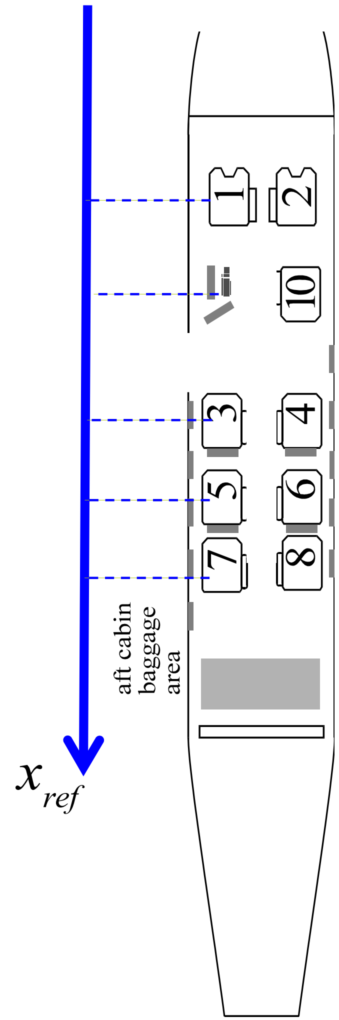


→ We can easily measure h, V_{IAS} , α, $Wfuel_{used}$ and T(temperature)….

→ and determine ρ, V_{TAS} and W

payload computations			
crew and pax	*[inches]*	*mass [lbs]*	*moment [lbsinches]*
seat 1	131		
seat 2	131		
seat 3	214		
seat 4	214		
seat 5	251		
seat 6	251		
seat 7	288		
seat 8	288		
seat 10	170		
baggage			
nose	74		
aft cabin	321		
	338		
payload			

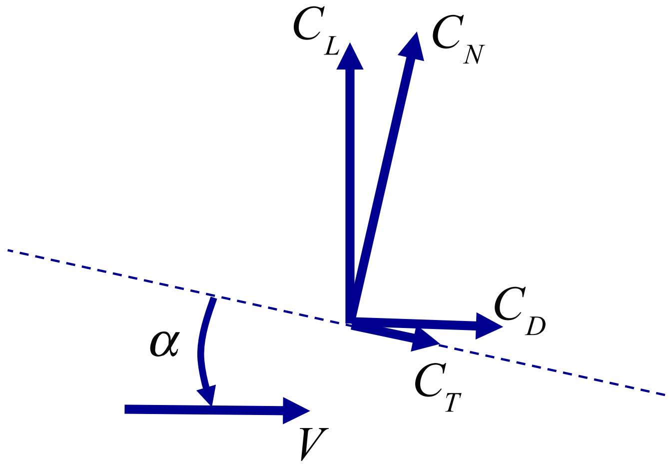
mass and balance computations		
item	*mass [lbs]*	*moment [lbsinches]*
basic empty mass		
$x_{cg_{datum}}$ at BEM = ____		
payload		
zero fuel mass		
$x_{cg_{datum}}$ at ZFM = ____		
fuel load		
ramp mass		
$x_{cg_{datum}}$ at RM = ____		



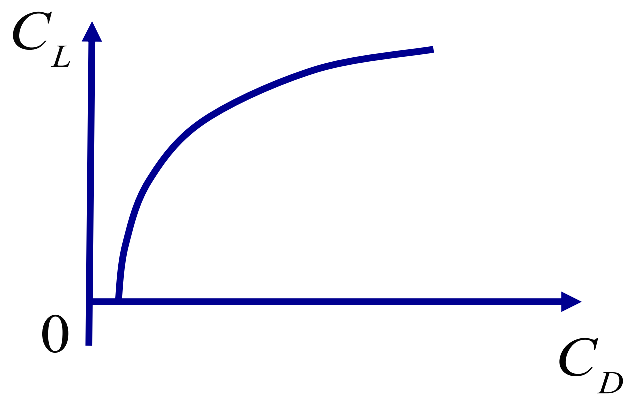
Aerodynamic coefficients

Steady, horizontal flight:

Horizontal equilibrium:



$$C_D = \frac{T}{\frac{1}{2}\rho V^2 S} = C_{D_0} + \frac{{C_L}^2}{\pi A e}$$

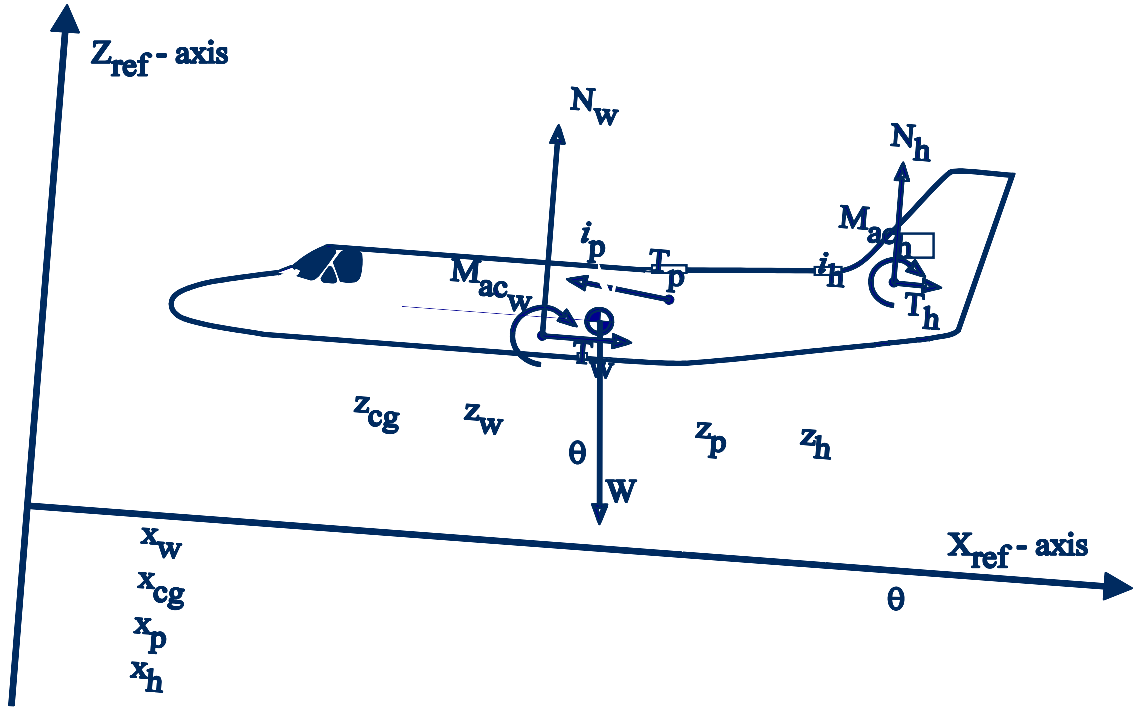


→ T, V and e can be determined from flight test data

Second measurement series

- Quasi-steady, horizontal flight
- Contstant thrust, varying altitude
- Small speedrange around V_{TR}
- One configuration
  - Gear up, flaps up

Forces and moments in symmetric flight



$$M = C_m \tfrac{1}{2} \rho V^2 S \bar{c}$$

Moment equilibrium

$$C_m = C_{m_0} + C_{m_\alpha}\left(\alpha - \alpha_0\right) + C_{m_\delta}\delta_e + C_{m_{\delta_f}}\delta_f + C_{m_{T_c}}T_c + C_{m_{\mathrm{lg}}}\Big|_{\mathrm{lg\ down}} = 0$$

Static stability for: $$C_{m_\alpha} = \frac{dC_m}{d\alpha} < 0$$

Normal pitch control: $$C_{m_\delta} = \frac{dC_m}{d\delta_e} < 0$$

Elevator trim curve $\delta_e - \alpha$

Equilibrium, landing gear up, flaps up

$$C_m = C_{m_0} + C_{m_\alpha}\left(\alpha - \alpha_0\right) + C_{m_\delta}\delta_e + C_{m_{\delta_{cf}}}\delta_{cf} + C_{m_{T_c}} T_c + C_{m_{lg}}\Big|_{\text{lg down}} = 0$$

Rewrite:

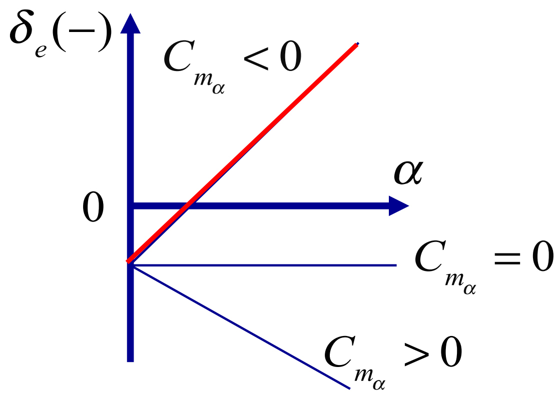
$$\delta_{e_{eq}} = -\frac{1}{C_{m_\delta}}\left\{C_{m_0} + C_{m_\alpha}\left(\alpha - \alpha_0\right) + C_{m_{Tc}} T_c\right\} = f(\alpha)$$

Slope:

$$\frac{d\delta_e}{d\alpha} = -\frac{1}{C_{m_\delta}} C_{m_\alpha}$$

$$\boxed{\frac{d\delta_e}{d\alpha} < 0}$$

Static stability



Test condition

Equilibrium, landing gear up, flaps up, constant thrust

$$C_m = C_{m_0} + C_{m_\alpha}\left(\alpha - \alpha_0\right) + C_{m_\delta}\delta_e + C_{m_{T_c}}T_c = 0$$

Rewrite:

$$\delta_{e_{eq}} = -\frac{1}{C_{m_\delta}}\left\{C_{m_0} + C_{m_\alpha}\left(\alpha - \alpha_0\right) + C_{m_{Tc}}T_c\right\} = f(\alpha)$$

Using Force Equilibrium W=N:

$$C_N \approx C_{N_\alpha}\left(\alpha - \alpha_0\right) \approx \frac{W}{\frac{1}{2}\rho V^2 S} \Rightarrow \left(\alpha - \alpha_0\right) = \frac{1}{C_{N_\alpha}}\frac{W}{\frac{1}{2}\rho V^2 S}$$

Elevator trim curve $\delta_e - V$

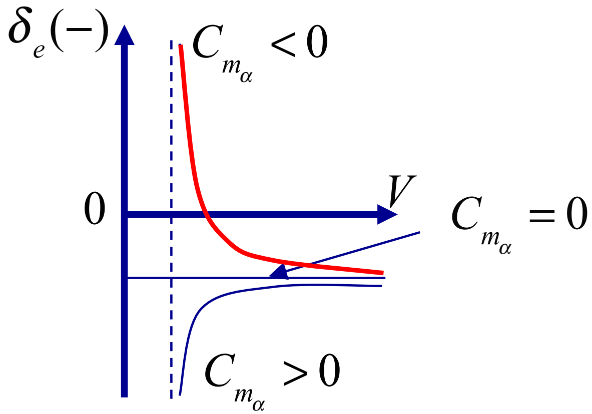
$$\delta_{e_{eq}} = -\frac{1}{C_{m_\delta}}\left\{C_{m_0} + \frac{C_{m_\alpha}}{C_{N_\alpha}}\frac{W}{\frac{1}{2}\rho V^2 S} + C_{m_{T_c}} T_c\right\} = f(V)$$

$\ominus$ $\oplus$

Slope:

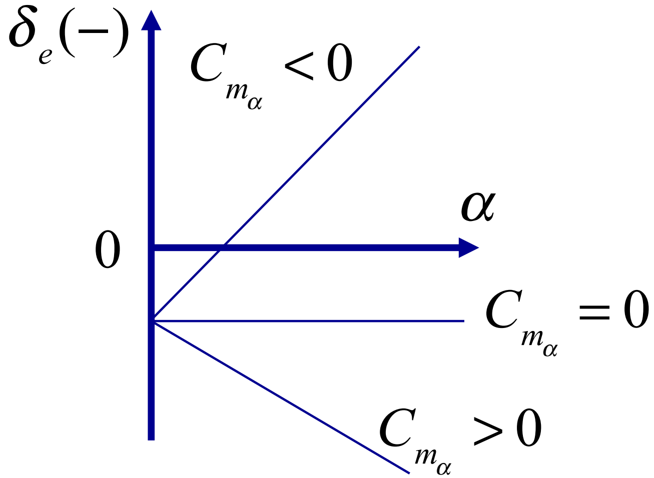
$$\frac{d\delta_e}{dV} = \frac{4W}{\rho V^3 S}\frac{1}{C_{m_\delta}}\frac{C_{m_\alpha}}{C_{N_\alpha}}$$

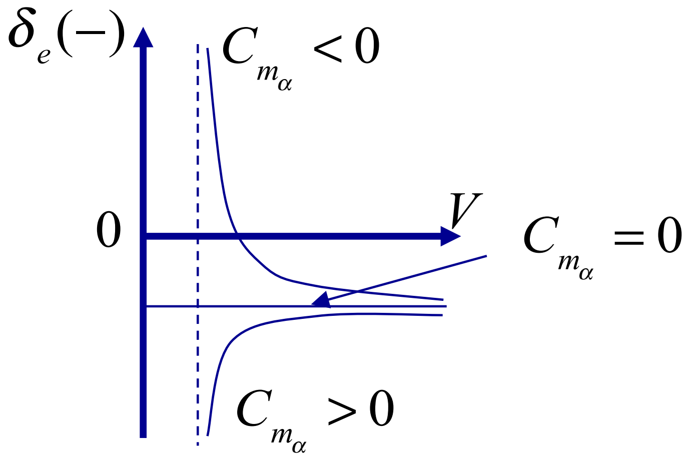
$\ominus$ $\oplus$



Static stabilty ($C_{m_\alpha} < 0$) for: $\dfrac{d\delta_{e_{eq}}}{dV} > 0$

Elevator trim curve





Static stabilty for: $\dfrac{d\delta_{e_{eq}}}{d\alpha} < 0$ $\qquad \dfrac{d\delta_{e_{eq}}}{dV} > 0$

→ We can easily measure *V*,*α* and *δ*$_e$

Elevator Trim Curve Measurements

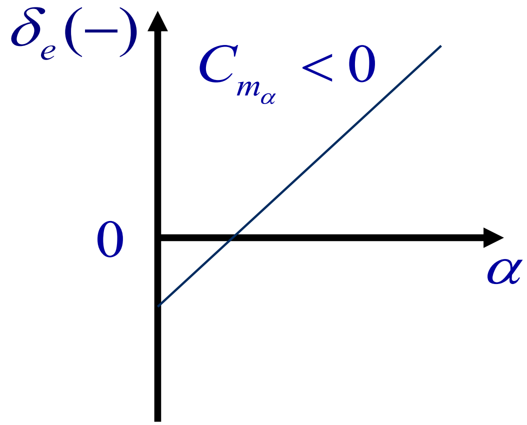
Quasi-steady, horizontal flight

Moment equilibrium: $C_m = 0$

Stable if: $\dfrac{dC_m}{d\alpha} = C_{m_\alpha} < 0$

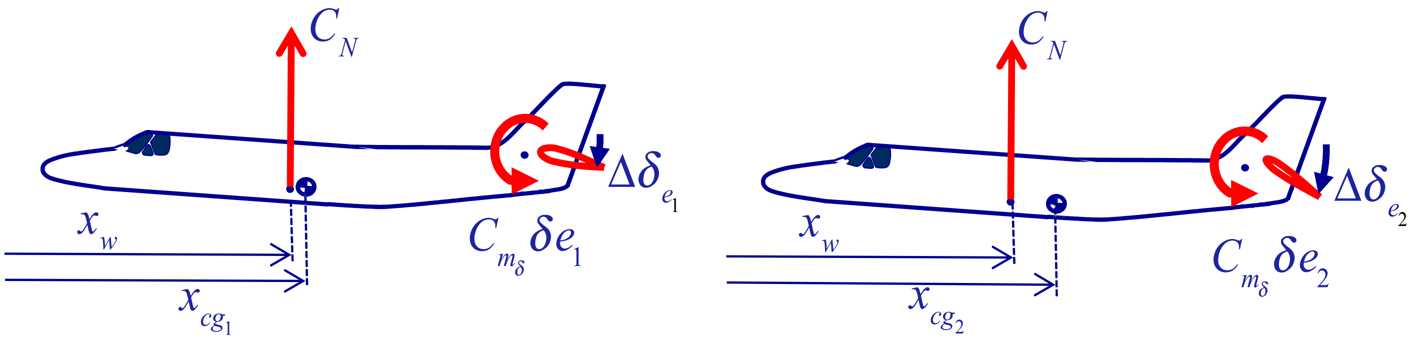
Slope: $\dfrac{d\delta_e}{d\alpha} = -\dfrac{1}{C_{m_\delta}} C_{m_\alpha}$

Long. stabilty: $C_{m_\alpha} = -\dfrac{d\delta_e}{d\alpha} C_{m_\delta}$



Determining elevator effectiveness C_{m_δ}

$$C_m = C_{m_0} + C_{m_\alpha}\Big|_{\delta_e=0}(\alpha-\alpha_0) + C_{m_\delta}\delta_e + C_{m_{\delta_f}}\delta_f + C_{m_{T_c}}T_c + C_{m_{lg}}\Big|_{\text{lg down}} = 0$$



$$\left.\begin{array}{l}\Delta C_m = C_{m_\delta}\cdot\Delta\delta_e \\[2ex] \Delta C_m = C_N\dfrac{x_{cg2}-x_{cg1}}{\bar{c}}\end{array}\right\} \quad C_{m_\delta} = -\frac{1}{\Delta\delta_e}C_N\frac{\Delta x_{cg}}{\bar{c}} \quad \text{with } C_N = \frac{W}{\frac{1}{2}\rho V^2 S}$$

Data reduction

<u>Test conditions</u>

- Uncontrollable variables — air temperature, density
- Adjustable variables — mass, cg
- Controllable variables — altitude, airspeed, angle of attack

In order to compare results data must be adjusted with respect to standard conditions

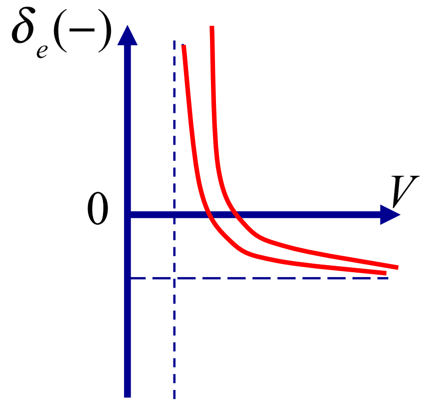
Reduced Airspeed

- We can determine V_c from V_i, using calibration data
- By converting V_c to the equivalent airspeed V_e , the atmospheric variables are reduced to ISA values
- V_e is the airspeed that gives the same dynamic pressure at sea level ISA, as the true airspeed V_t at altitude

$$q = \tfrac{1}{2}\rho V_t^2 = \tfrac{1}{2}\rho_0 V_e^2 \approx \tfrac{1}{2}\rho_0 V_c^2$$

Reduced elevator trim curve $\delta_e^* - \tilde{V}_e$

$$\delta_{e_{eq}} = -\frac{1}{C_{m_\delta}}\left\{C_{m_0} + \frac{C_{m_\alpha}}{C_{N_\alpha}}\frac{W}{\frac{1}{2}\rho V^2 S} + C_{m_{T_c}} T_c\right\}$$



Data points for V = 120 m/s:

	δ_e
m = 6200 kg	-0.4
m = 4742 kg	-0.6

Reduced EAS: $\tilde{V}_e = V_e\sqrt{\frac{W_s}{W}}$

Building the mathematical model

- Based on flight dynamics theory
- Use parameters derived from flight test data
- Verify the model by using known data points
- Validate the model against dynamic flight test data
- Predict dynamic behavior

State Space Representation

General Form:

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

x	**- state vector**	**A**	**- state matrix**
y	**- output vector**	**B**	**- input matrix**
u	**- input vector**	**C**	**- output matrix**
		D	**- direct matrix**

State Space Representation

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

- **very compact notation**
- **we can apply linear algebra**
- **computers can easily work with matrices**

Solution of the equations

$$\dot{x} = Ax$$

General solution:

$$\bar{x}(t) = ce^{\lambda t}\bar{v}$$

System behavior (λ is real):

$$\lambda > 0 \qquad\qquad \lambda < 0$$

Eigenvalues and stability

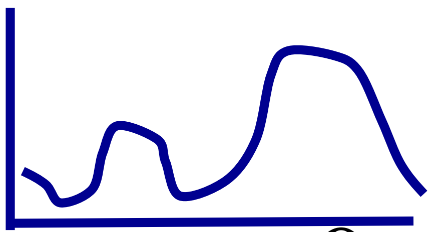
$$\overline{x}(t) = ce^{\lambda t}\overline{v}$$

Complex eigenvalues:

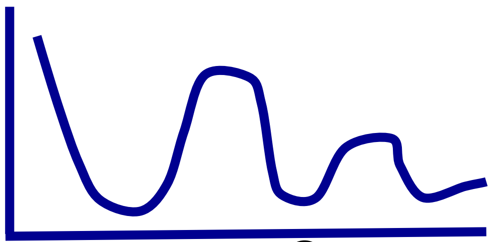
$$\lambda = a + ib$$

$$\Rightarrow \overline{x}(t) = ce^{(a+ib)t}\overline{v} = ce^{at}(\cos b + i \sin b)\overline{v}$$

System behavior real part:



$a > 0$

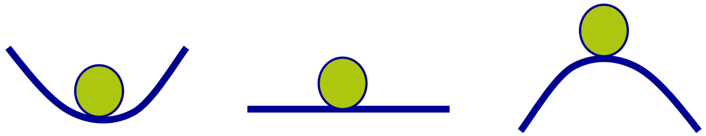


$a < 0$

Eigenvalues and stability

$$Ax = \lambda x$$

Positive real part	undamped
Negative real part	damped
Imaginary part	oscilatory



Longitudinal EOM

Linearized, homogenous, deviation equations for symmetric motions:

$$\begin{bmatrix} C_{X_u} - 2\mu_c D_c & C_{X_\alpha} & C_{Z_0} & 0 \\ C_{Z_u} & C_{Z_\alpha} + \left(C_{Z_{\dot{\alpha}}} - 2\mu_c\right) D_c & -C_{X_0} & C_{Z_q} + 2\mu_c \\ 0 & 0 & -D_c & 1 \\ C_{m_u} & C_{m_\alpha} + C_{m_{\dot{\alpha}}} D_c & 0 & C_{m_q} - 2\mu_c K_Y^2 D_c \end{bmatrix} \begin{bmatrix} \hat{u} \\ \alpha \\ \theta \\ \frac{q\bar{c}}{V} \end{bmatrix} = \underline{0}$$

- Eigenvalues describe stability of short period and phugoid
- Derivation will be treated in week 3.5

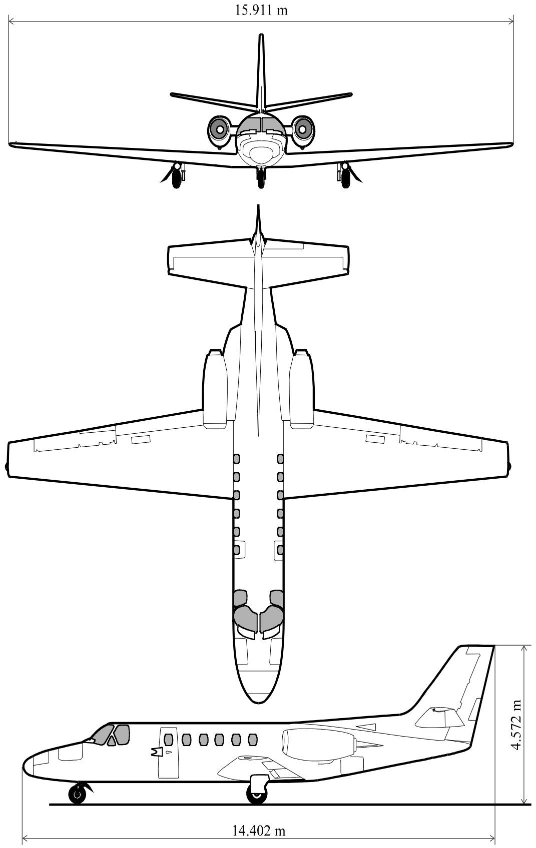
Lateral EOM

Linearized, homogenous, deviation equations for asymmetric motions:

$$\begin{bmatrix} C_{Y_\beta} + \left(C_{Y_{\dot\beta}} - 2\mu_b\right) D_b & C_L & C_{Y_p} & C_{Y_r} - 4\mu_b \\ 0 & -\frac{1}{2}D_b & 1 & 0 \\ C_{\ell_\beta} & 0 & C_{\ell_p} - 4\mu_b K_X^2 D_b & C_{\ell_r} + 4\mu_b K_{XZ} D_b \\ C_{n_\beta} + C_{n_{\dot\beta}} D_b & 0 & C_{n_p} + 4\mu_b K_{XZ} D_b & C_{n_r} - 4\mu_b K_Z^2 D_b \end{bmatrix} \begin{bmatrix} \beta \\ \varphi \\ \frac{pb}{2V} \\ \frac{rb}{2V} \end{bmatrix} = \underline{0}$$

- Eigenvalues describe stability of aperiodic roll, spiral and Dutch roll
- Derivation will be treated in week 3.5

Symmetric / asymmetric eigenmotions



Asymmetric

forces and moments: Y, L, N

angular rates: p, r

angles: β, φ

Symmetric

forces and moments: X,Z,M

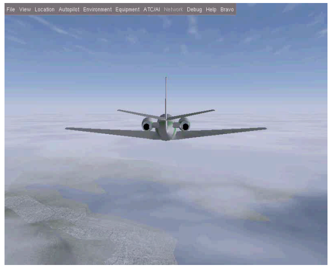
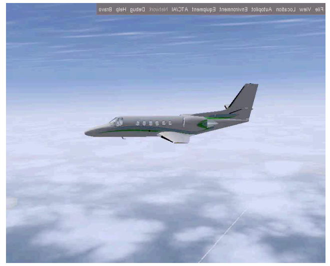
angular rates: q

angles: α, θ

Eigenmotions

Symmetric

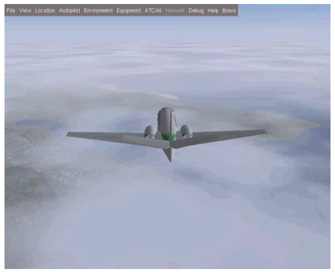
- **Short period**
- **Phugoid**

Asymmetric

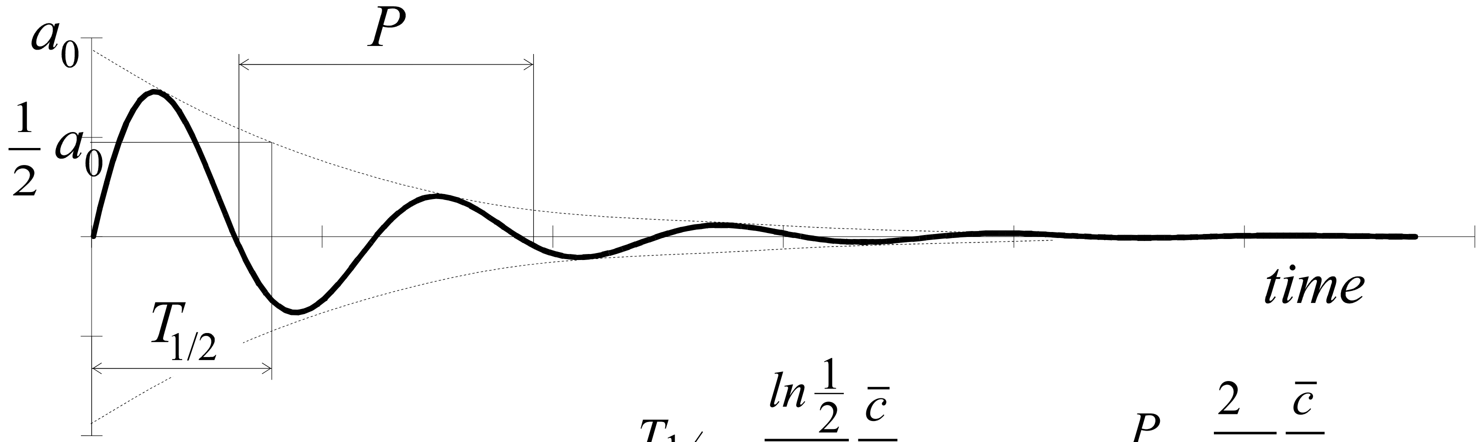
- **A-periodic roll**
- **Spiral**
- **Dutch roll**






Validating the model

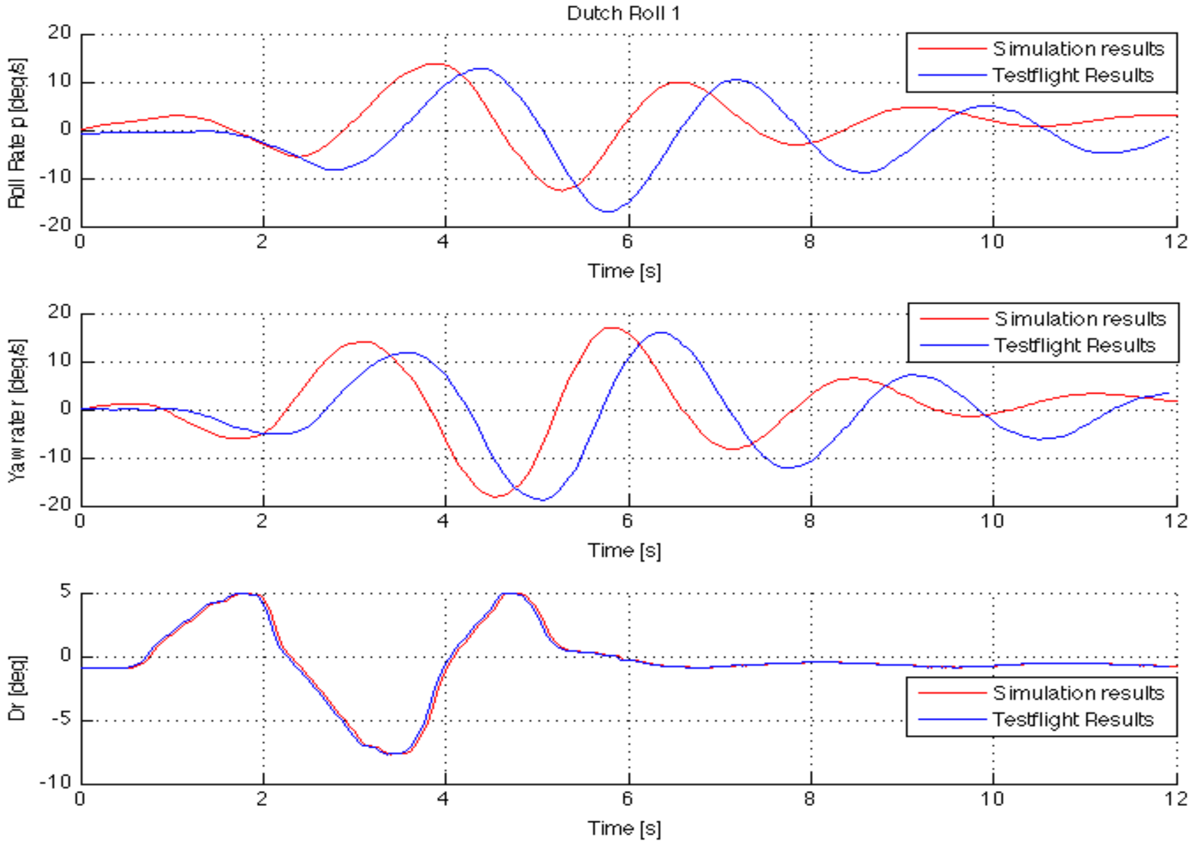
- Compare model properties with observed behaviour



$$T_{1/2} \quad \frac{\ln\frac{1}{2}}{c}\,\frac{\bar{c}}{V} \qquad\qquad P \quad \frac{2}{c}\,\frac{\bar{c}}{V}$$

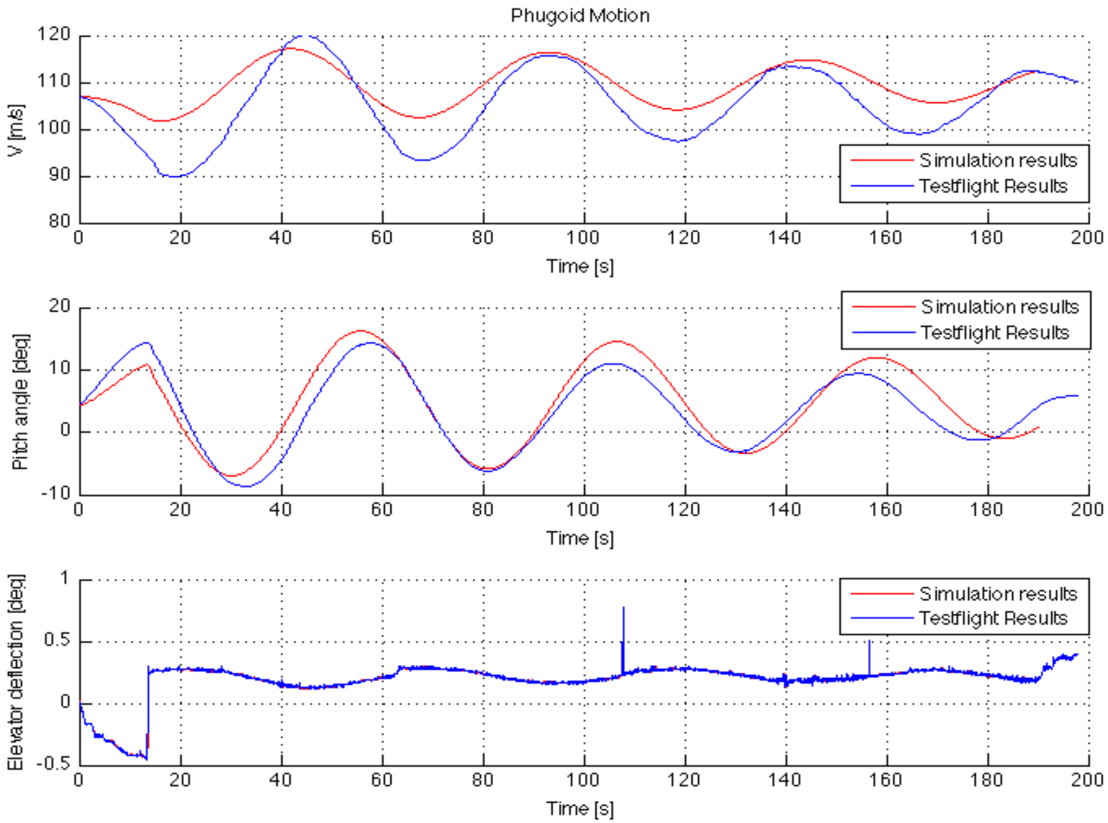
Validating the model

- Compare predicted behaviour to test data



Improving the model

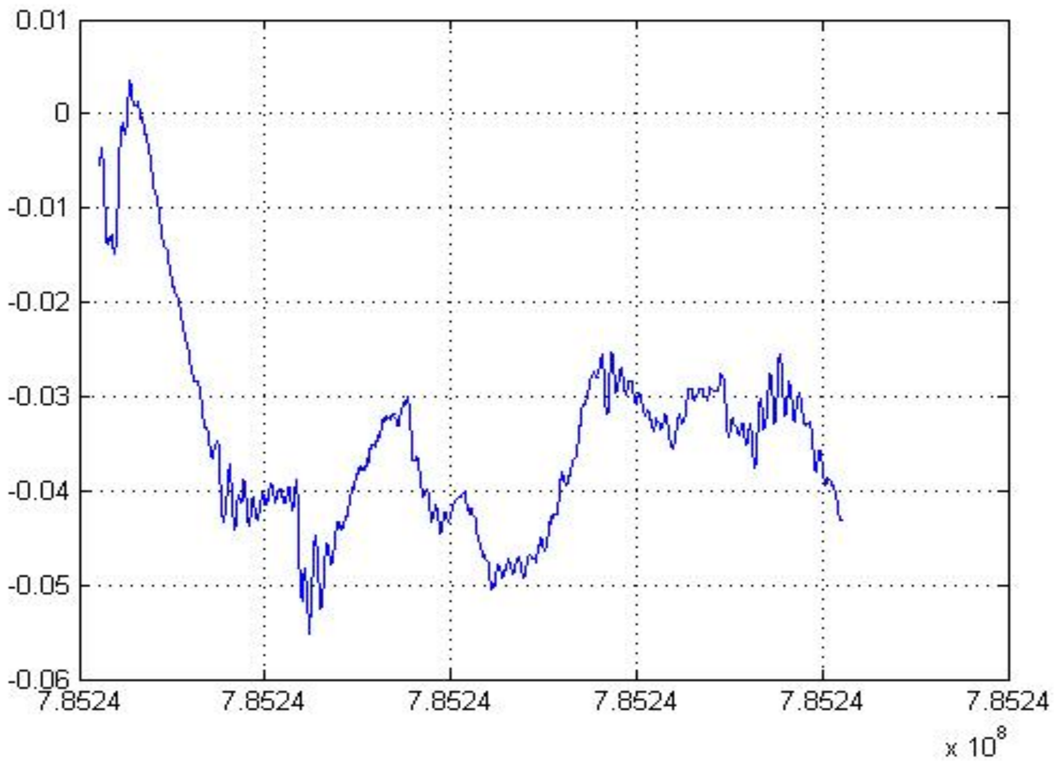
- Change model parameters to get a better match



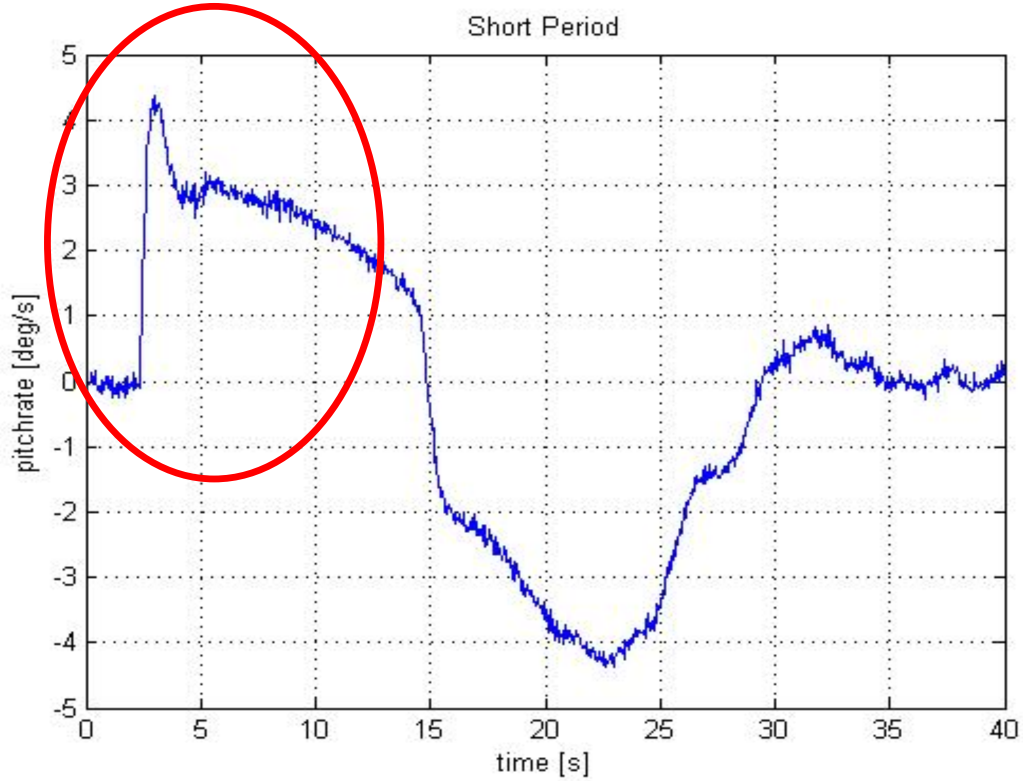
Pointers for the report

- Correct usage of units
- Use only relevant measurements
- Significant digits

How not to present your data



How not to present your data



Overview

- Corona protocol
- Registration flow
- Fligt Test logisitcs
- Flight Dynamics assignment
- Short Recap
- Online test

Recap

1. Sign-up for a test flight
2. Schedule a PCR-test at GGD Haaglanden, test location **Delft** or **Rijswijk** within two days of your flight
3. Join the SVV intro lecture on March 1
4. Bring test results to the test flight
5. Bring your **passport** or **EU ID card** to the test flight

Last points

- Questions about
  - Flight test: Alexander
  - SVV groups: Wouter
- Sign up for a flight
- Schedule a PCR test
- **Don’t forget your passport**
- **Don’t forget your PCR test result**
- Have fun!

Overview

- Corona protocol
- Registration flow
- Fligt Test logisitcs
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Online Test

- Serves as proof that you attended today's Briefing lecture
- You need 70% score (max two mistakes)
- Go to:
  BrightSpace → AE3212-I FD → Content → Test Flight → Online Test
- Good luck!

AE3212-II

Flight Dynamics Assignment and Flight Briefing