Using Simulators in the Design Process

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RAeS General Aviation Group
Light Aircraft Design Conference
Methods and Tools
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Introductions

- Dr. M. Jump
- BEng Aeronautical Engineering, University of Bristol 1994
- Aerodynamicist BAE Systems
- PhD (Pilot Guidance Displays), University of Liverpool, 2007
- Lecturer 2007 – 2014, Senior Lecturer 2014 – date, Aerospace Engineering
- PPL since 1997
- Studying/training for IMC

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Aircraft Design at UoL

- Aircraft Design and Aerospace Capstone Project → to provide aircraft design exercises that require the **INTEGRATION** of knowledge and skills learned throughout the degree programme.

- Aircraft Design (Year 3, BEng (optional) and MEng (compulsory))
  - Learn the tools/methods and techniques to...
  - **Perform a conceptual design against a requirement**

- Aerospace Capstone Design Project (Year 4, MEng and MSc)
  - **Perform a conceptual design against a requirement** and then**...**
  - Perform a detailed analysis of the conceptual design (aerodynamics, avionics, flight dynamics, structures.....etc.)

- **Simulation and simulators used throughout**

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Aircraft Design – Art and Engineering

"*A beautiful aircraft is the expression of the genius of a great engineer who is also a great artist*"

Shute N., *No Highway*, 1947

"*Airplane design is the intellectual engineering process of creating…a flying machine to (1) meet certain specifications and requirements established by potential users (or as perceived by the manufacturer) and/or (2) pioneer innovative, new ideas and technology*"

Anderson Jr., J.D., Aircraft Performance and Design, 1999

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Simulation/Simulator

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that **a model** be developed; this model represents the key characteristics or behaviours of the selected physical or abstract system or process. The model represents the system, whereas the simulation represents the operation of the system over time.

Wikipedia

A Simulator is a machine for simulating certain environmental and other conditions for the purposes of training or **experimentation**

http://dictionary.reference.com/browse/simulator

"All models are wrong, some are useable"

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Design Phases

1. **Requirements Capture**
   a list of expectations that the aircraft must meet
2. **Conceptual Design**
   formally establishes the initial idea
3. **Preliminary Design**
   ultimately answers whether the idea is viable or not
4. **Detail Design**
   converts the preliminary design into something that can be built and flown. Start of construction of the proof-of-concept (poc) aircraft
5. **Proof-of-concept aircraft construction and design**
   culminates with the maiden flight of the poc aircraft

Adapted from: Gudmundsson, S., General Aviation Aircraft Design, Butterworth-Heinemann, 2014

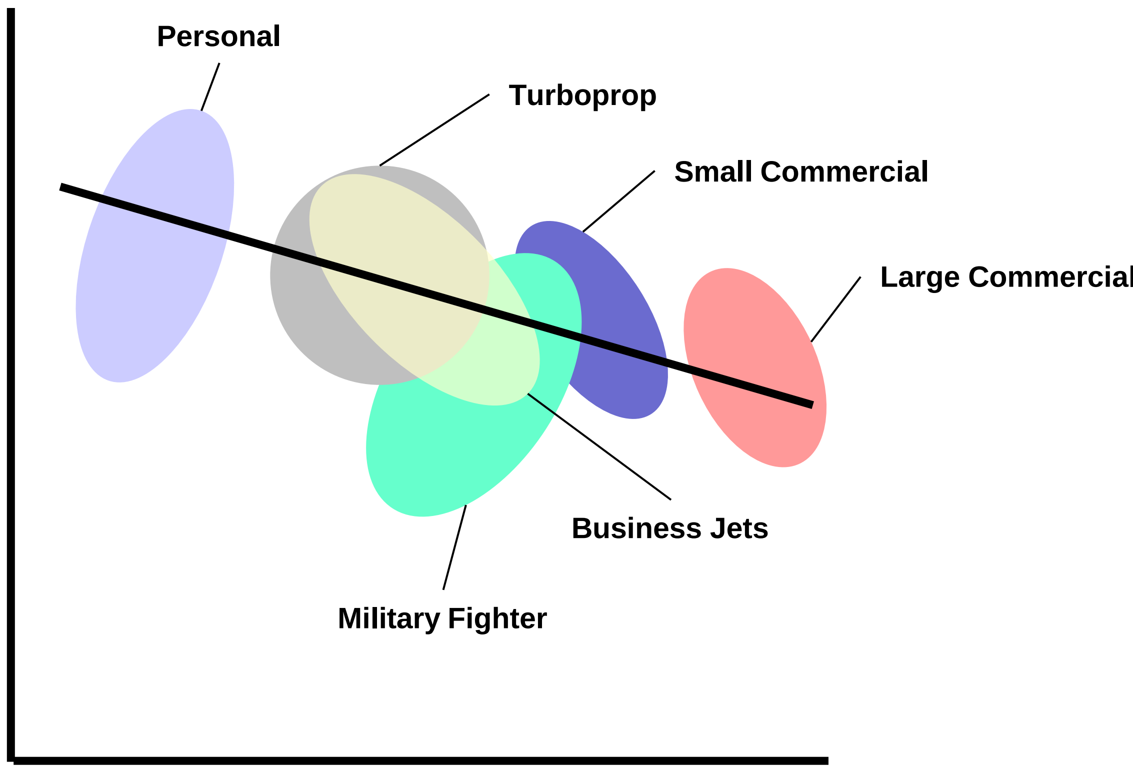
Modelling

- So, before we can do some ‘simulating’ we need a system model
- 2 examples
  - 1 from concept design phase
  - 1 from preliminary/detail design phase
- Once we have the models for these, we can exercise them through time

Modelling 1 – Take-Off Weight Estimation

Structure Factor

$$s = \frac{W_{empty}}{W_{TO}}$$



W_{TO}

$$\frac{W_{land}}{W_{TO}} = \frac{W_{land}}{W_{loiter}} \cdot \frac{W_{loiter}}{W_{cruise}} \cdot \frac{W_{cruise}}{W_{accel}} \cdot \frac{W_{accel}}{W_{climb}} \cdot \frac{W_{climb}}{W_{TO}}$$

(Corke, T.C., Design of Aircraft)

Modelling 1 – Take-Off Weight Estimation

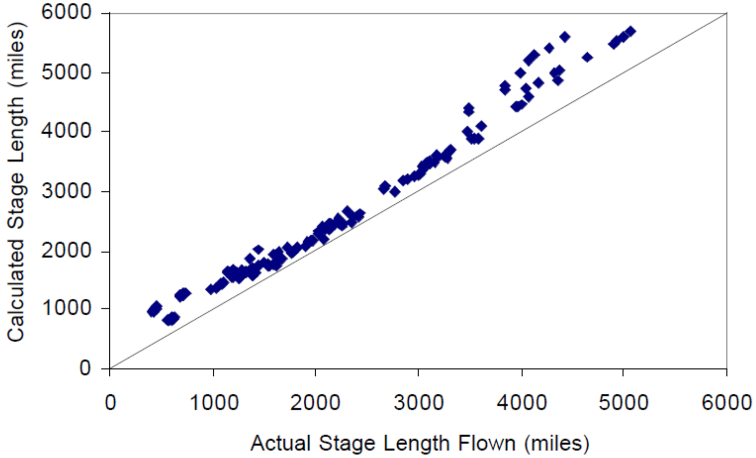
- So, problem boils down to:
  - Selecting an appropriate Structure Factor, '*s*'
  - Computing or estimating values for each Fuel Fraction
- For example:
  - Empirical (Start Up and Take-Off):

$$0.97 \le \frac{W_{cruise}}{W_{take\text{-}off}} \le 0.975$$

  - Computed (Cruise):

$$\text{Range(nm)} = \frac{V}{C}\frac{L}{D}\ln\left[\frac{W_{loiter}}{W_{cruise}}\right]$$

(16 short- and long-haul aircraft)



(J. J. Lee, MIT Masters Thesis, 2000)

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Simulation 1 – Take-Off Weight Estimation

- To simulate through time, we can now iterate
  - Guess W_{TO} to give an estimated empty weight: $W'_{empty} = s \times W_{TO_{guess}}$
  - Run aircraft through mission using fuel fractions:

$$\frac{W_{land}}{W_{TO\,guess}} = \frac{W_{land}}{W_{loiter}} \cdot \frac{W_{loiter}}{W_{cruise}} \cdot \frac{W_{cruise}}{W_{accel}} \cdot \frac{W_{accel}}{W_{climb}} \cdot \frac{W_{climb}}{W_{TO\,guess}}$$

$$W''_{empty} = W_{TO_{guess}} - W_{land}$$

  - Compare W'_{empty} with W''_{empty}
  - Modify $W_{TO_{guess}}$ appropriate and repeat until $W'_{empty} = W''_{empty}$

- This is amenable to a spreadsheet analysis

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Simulation 1 – Take-Off Weight Estimation

	A	B	C	D	E	F	G	H	I
1		Mission Requirements							
2									
3	Max. Mach	2.1							
4	Cruise Mach	2.1							
5	Cruise Alt. (ft)	55,000							
6	Oper. Rad. (nm)	2,000							
7	Engine: TSFC Min.	0.9							
8	Engine: TSFC Max.	2.17							
9	Engine: Thrust (lbs)	108,540							
10	Aspect Ratio	2							
11	Combat: Time (min)	0							
12	Combat: Altitude (ft)	30,000							
13	Loiter: Time (min)	10							
14	Loiter: Altitude (ft)	0							
15	Fuel Reserve (%)	5							
16	Trapped Fuel (%)	1							
17	Structure Factor	0.5							
18									
19	Payload: Exp. (lb)	0							
20	Payload: Non-exp. (lb)	4000							
21									
22			Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Iteration 7
23	Weight: T-O (estimated)	40,000	40,000.00	42,232.50	90,523.17	90,523.17	#DIV/0!	#DIV/0!	#DIV/0!
24	Weight: T-O (final)		42,232.50	44,3[illegible].34	90,523.17	90,523.17	#DIV/0!	#DIV/0!	#DIV/0!
25	Surplus Empty Wt. (lbs)		-2,232.50	-2,133.85	0.00	0.00	#DIV/0!	#DIV/0!	#DIV/0!
26									
27	1. Start-up & T-O		39,000.00	41,176.68	88,260.09	88,260.09	#DIV/0!	#DIV/0!	#DIV/0!
28	2. Climb & Accel. to Cruise		36,158.00	38,170.79	81,817.10	81,817.10	#DIV/0!	#DIV/0!	#DIV/0!
29	3a. L/D		7.59	7.59	7.59	7.59	7.59	7.59	7.59
30	3b. V (f/s)		[illegible]5.70	1,925.70	1,925.70	1,925.70	1,925.70	1,925.70	1,925.70
31	3c. Cruise to destination		[illegible]4.58	31,003.49	66,454.38	66,454.38	#DIV/0!	#DIV/0!	#DIV/0!
32	4. Accel. to high speed		[illegible]4.58	31,003.49	66,454.38	66,454.38	#DIV/0!	#DIV/0!	#DIV/0!
33	5. Combat		[illegible]4.58	31,003.49	66,454.38	66,454.38	#DIV/0!	#DIV/0!	#DIV/0!
34	6. Drop Exp. Payload		29,364.58	31,003.49	66,454.38	66,454.38	#DIV/0!	#DIV/0!	#DIV/0!
35	7. Cruise back		23,850.82	25,182.00	53,976.30	53,976.30	#DIV/0!	#DIV/0!	#DIV/0!
36	7. Loiter		23,3[illegible].13	24,689.26	52,920.15	52,920.15	#DIV/0!	#DIV/0!	#DIV/0!
37	8. Land		22,799.53	24,072.03	51,597.15	51,597.15	#DIV/0!	#DIV/0!	#DIV/0!
38									
39	Total Fuel Wt. (lbs)		18,232.50	19,250.10	41,261.58	41,261.58	#DIV/0!	#DIV/0!	#DIV/0!
40	Available Empty Wt. (lbs)		17,767.50	18,982.40	45,261.58	45,261.58	#DIV/0!	#DIV/0!	#DIV/0!
41	Required Empty Wt. (lbs)		20,000.00	21,116.25	45,261.58	45,261.58	#DIV/0!	#DIV/0!	#DIV/0!

Input Data

Initial W_{TO} guess

Revised W_{TO} guess

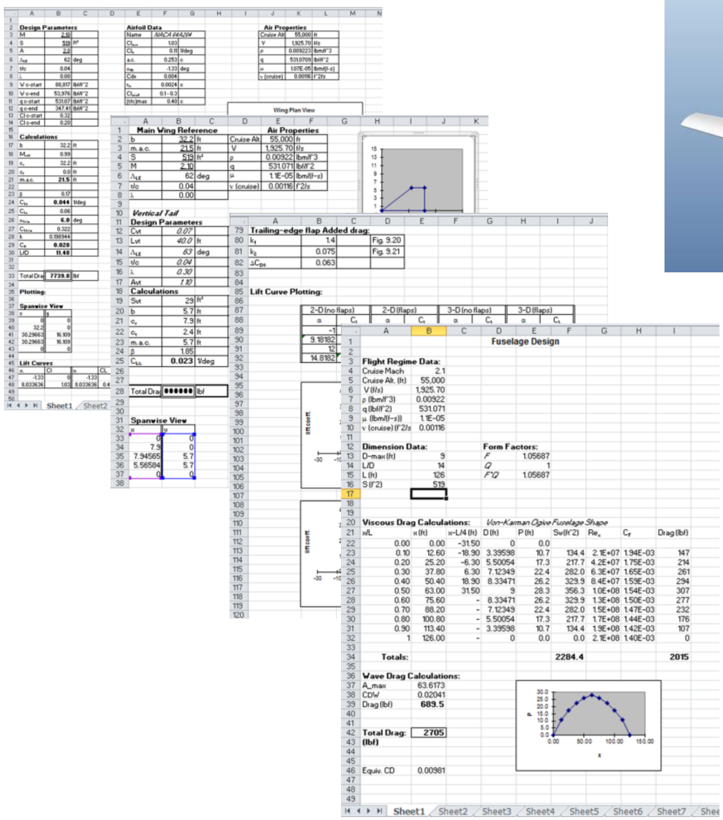
Final W_{TO} estimate

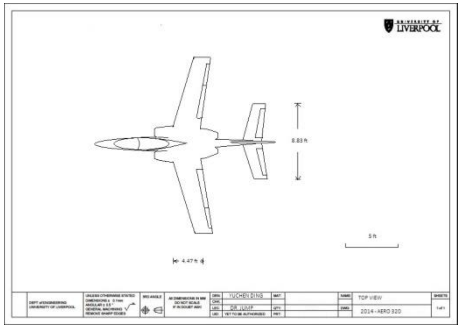
W'_{empty} c.f. W''_{empty}

First Simulation

Simulation 1 – Take-Off Weight Estimation

- ITERTOW.xls Demo





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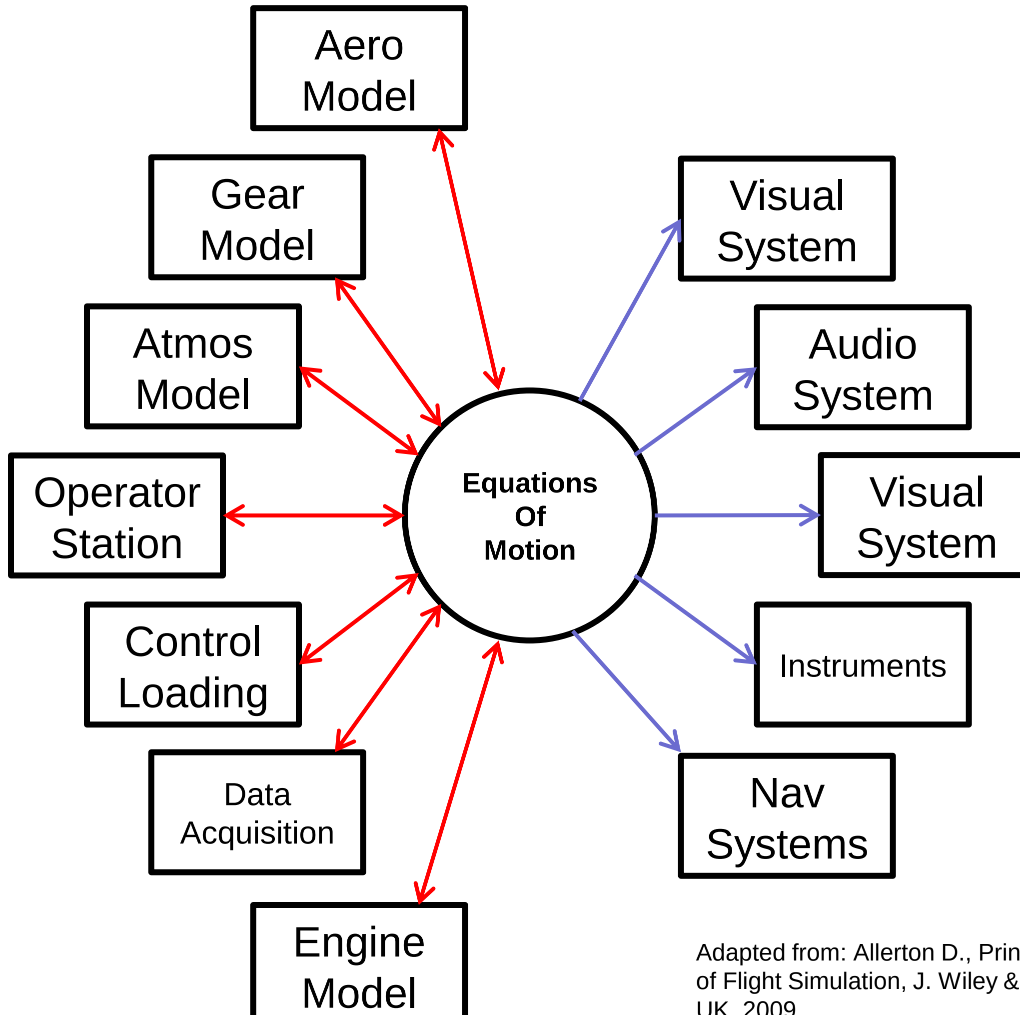
Modelling 2 – Handling Qualities Analysis

- Of course, ‘simulator’ conjures up an image of something more than a spreadsheet…



Adapted from: Allerton D., Principles of Flight Simulation, J. Wiley & Sons, UK, 2009

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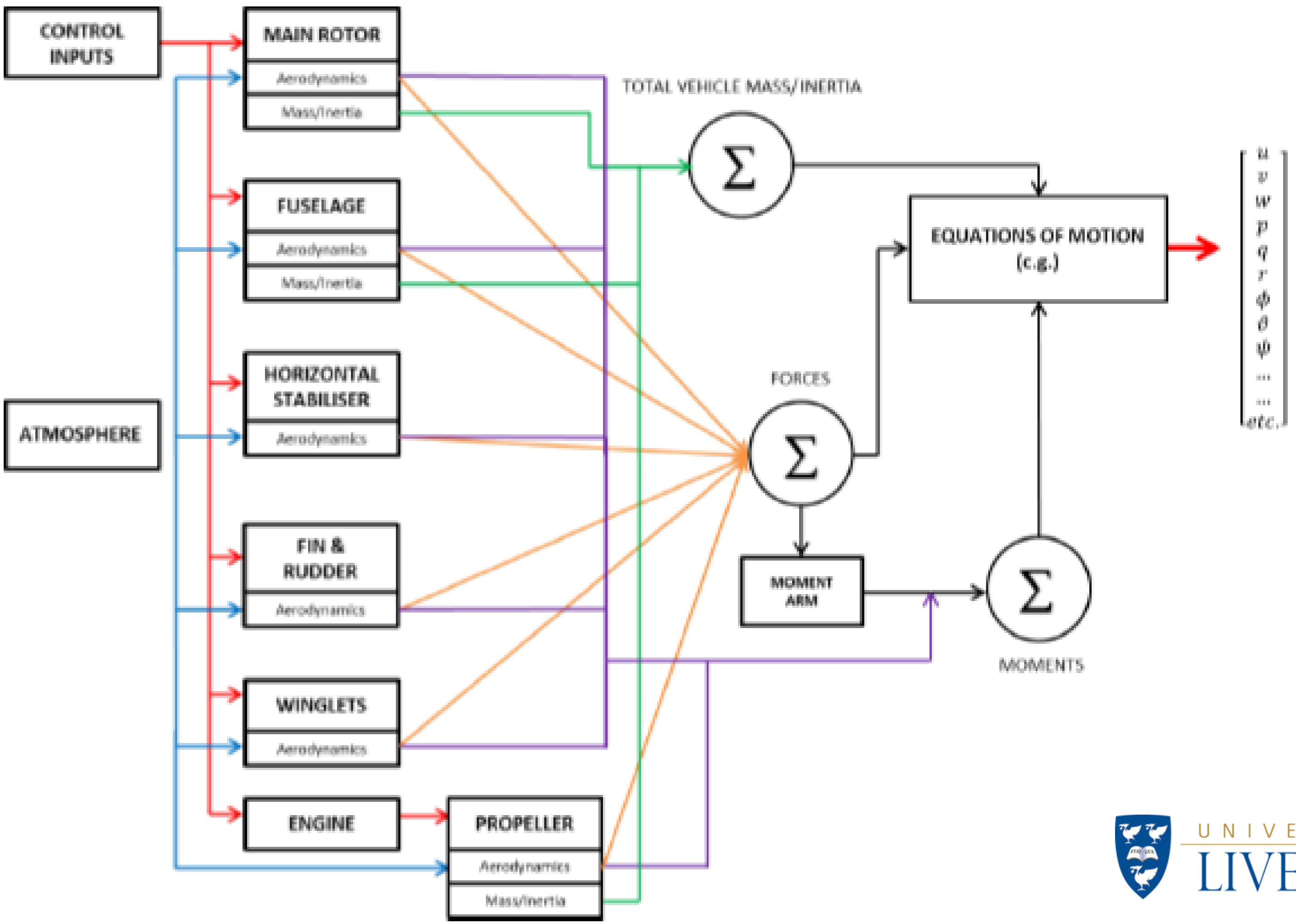
Modelling 2 – Handling Qualities Analysis

- Need a flight dynamics model…many ways to construct them



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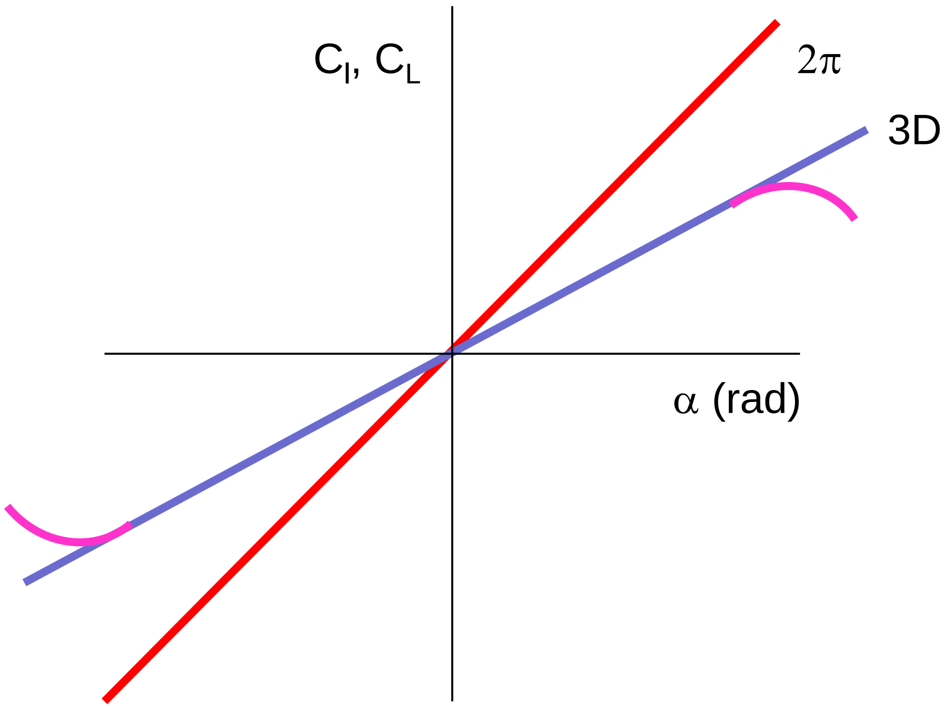
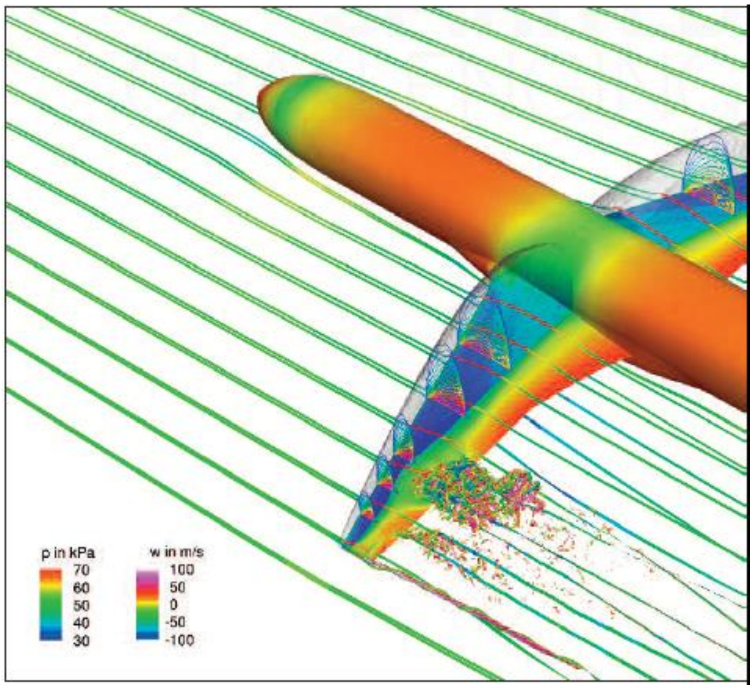
Modelling 2 – Handling Qualities Analysis

- Each component can be modelled at as high a level of fidelity as is necessary. What are you trying to achieve?
- Real time or not?





Look-up tables or ‘on-the-fly’ computation?

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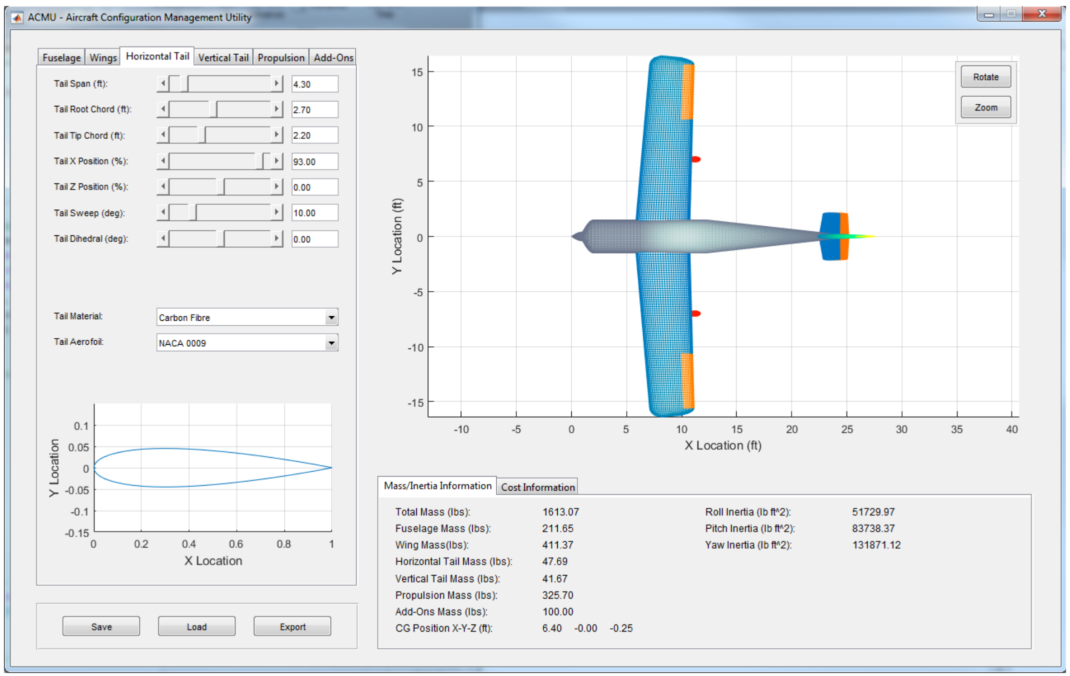
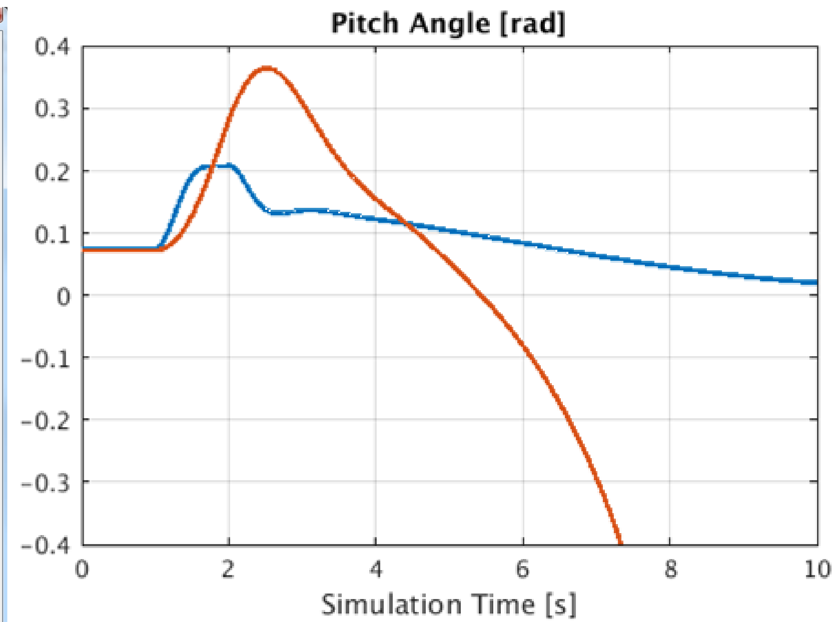
Simulation 2 – Handling Qualities Analysis

- But how can simulators/the simulation model be used?
- To help enable design decisions to mature the design…
- …by rapid prototyping of the vehicle





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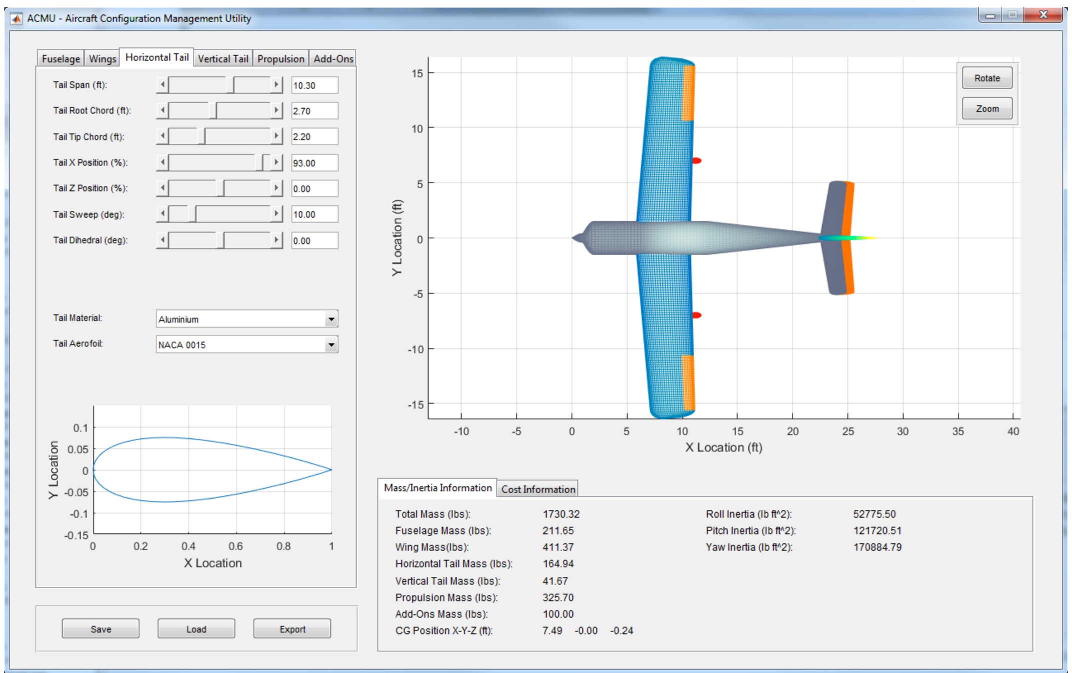
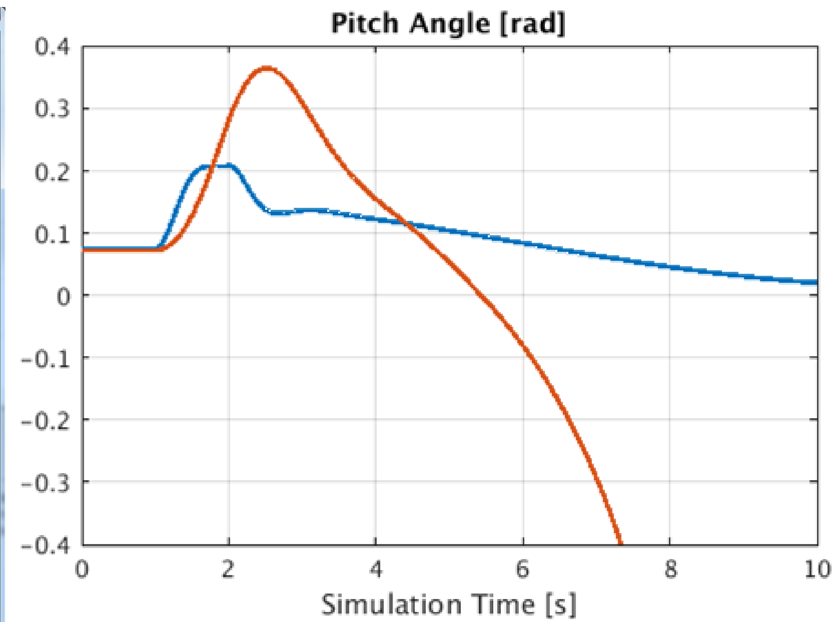
Simulation 2 – Handling Qualities Analysis

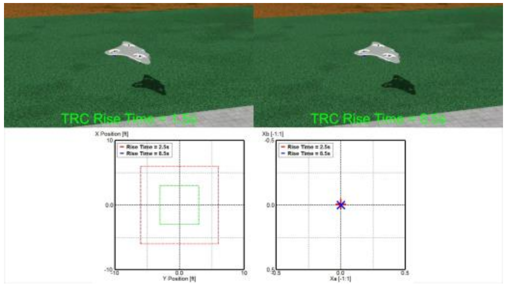
- Design modified through the use of a (MATLAB) GUI
- Off-line non-linear analysis re-computed (faster than real-time)
- ‘Better’ response due to increased tail size





Simulation 2 – Handling Qualities Analysis

- Once we have the design at our desired level of maturity…
- …we can put a pilot in the loop and go flying, using the same model
- (or you could use a pilot model)
- To ascertain the vehicle's assigned handling qualities
- To answer design parameter questions
- Etc.



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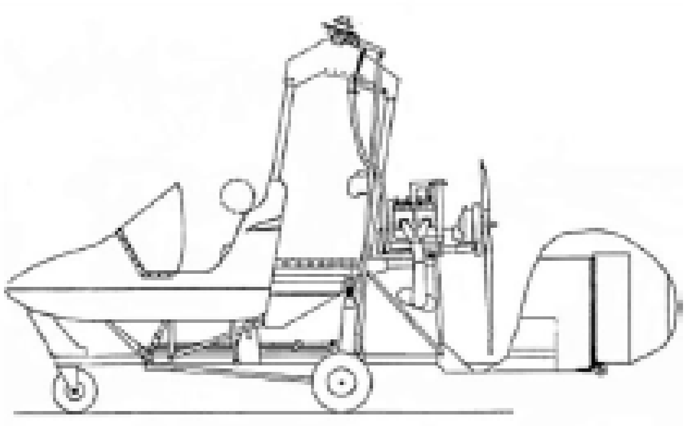
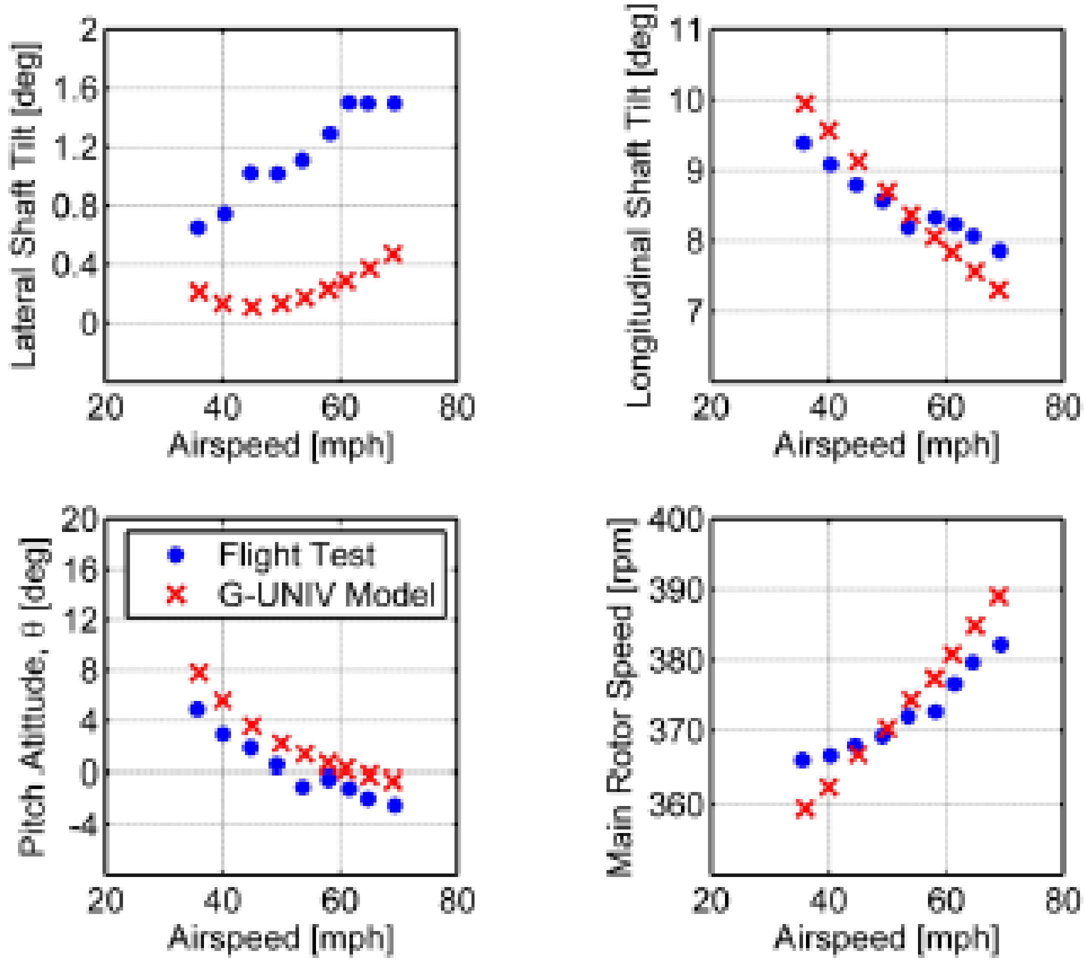
Modelling 2 – Handling Qualities Analysis

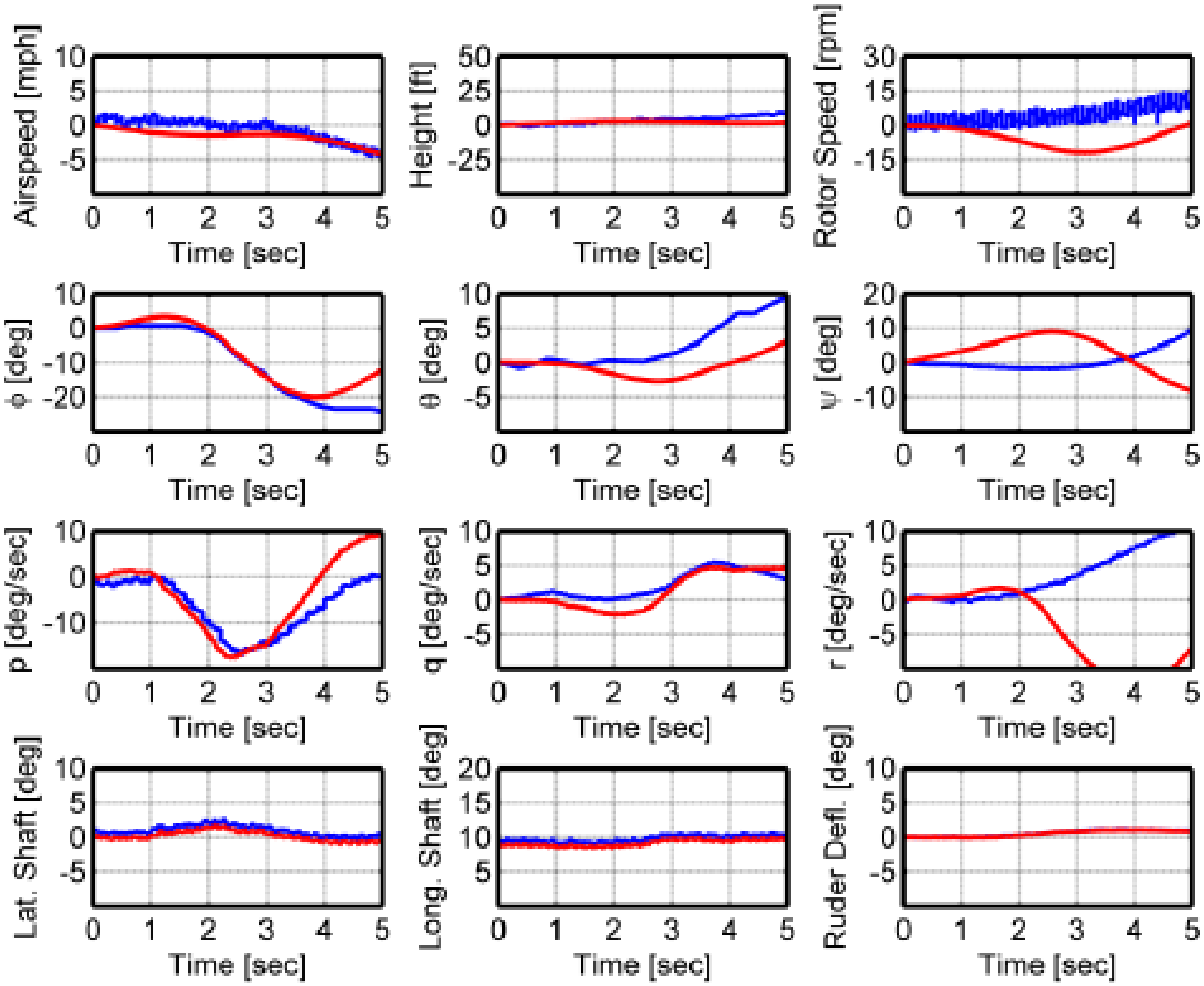
- Back to what are you trying to achieve?
- HQ example for autogyro





Modelling 2 – Handling Qualities Analysis

- Dynamic responses…



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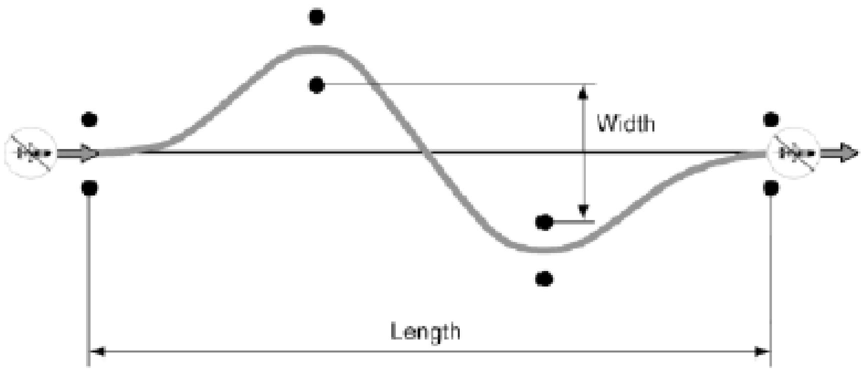
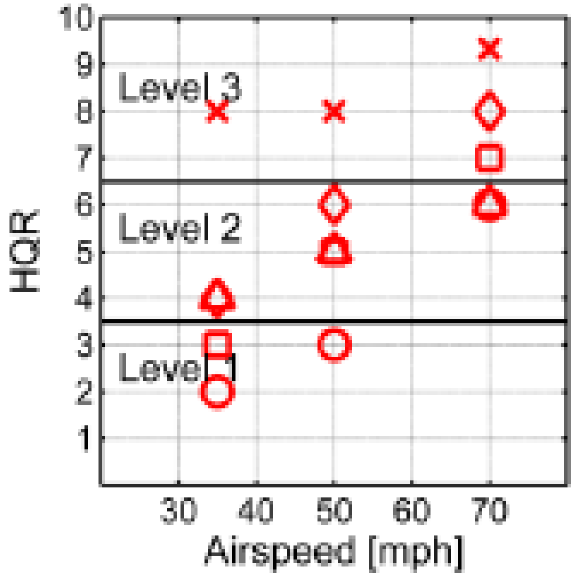
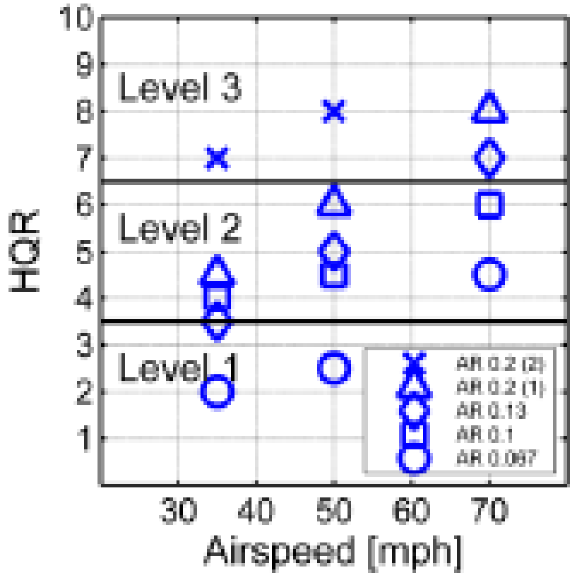
Modelling 2 – Handling Qualities Analysis

- Re-created a real flight trial in the simulator







Robinson R. and Jump M., Progress in the Development of Handling Qualities Critical Design Guidelines for an Autogyro, Proceedings of the American Helicopter Society Forum, Forum 67, Virginia Beach VA, 2011.

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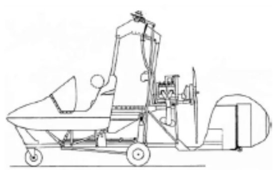
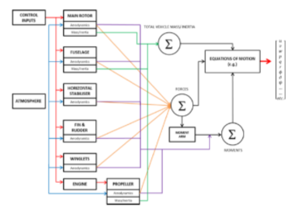
COTS Flight Simulators for the Designer

- There are a number of COTS flight simulators available
- See: McGovern S.M. and Cohen S.B., Survey of contemporary aircraft fight dynamics models for use in airspace simulation, SPIE 6564, Modeling and Simulation for Military Operations II, 65640V (10 May 2007); doi: 10.1117/12.719696
- For design purposes, any simulator where you have to tell it how the vehicle should fly is of little value e.g. using stability derivatives
- One that does not do this is Laminar Research X-Plane (current V10)
- It derives the aerodynamic model from the geometry etc.

COTS Flight Simulators for the Designer



Plane Maker



Blade Element (Momentum) Theory (BET)

BET aero are 2D so corrections for:

- 2D → 3D lift curve slope
- 2D → 3D C_{Lmax} reduction
- Induced drag correction
- Moment reductions due to AR, taper…
- Compressible flow

- But we know that 'all models are wrong, some are useable'
- Have mentioned some limitations already (2D etc.)
- Are corrections applied plausible? What are their limitations?
- Others
  - Airflow is always in equilibrium, flow adapts instantly to any changes
  - Theory breaks down for large deflections e.g. stall
- BUT, if you don't expect to encounter such conditions, then it may yield useful results

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See: http://wiki.x-plane.com/Appendix_A:_How_X-Plane_Works

Other Uses

- Other design items that simulators can be useful for:
  - Cockpit layout assessment
  - Flight control system design
  - Avionics assessment
  - Human factors studies
  - Etc.
  - Etc.

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Key Points

- Simulation is the exercising of a model through time
- Can be used in all phases of design to answer ‘what if’ early in the process
- Can be used to predict and verify e.g. performance against requirements
- All models are wrong, some are useable
- Need to understand the capailities and limitations of the model

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  - Dr. Mark White
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  - Dr. Sophie Robinson
  - Mr. Tom Fell
  - Mr. Chris Dadswell
  - The Aircraft Design and Capstone cohorts from the past few years

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ANY QUESTIONS ?

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