

Longitudinal Aircraft Dynamics #9 – finalizing the dynamics – preliminary validation

by George Lungu

- This section continues with the dynamics formulas governing our 2D plane.

Worksheet lever calculation formulas:

- Copy the last worksheet and name the new one “Longitudinal Stability_Model_5”

- There are three buttons, the “Reset”, the “Run_Pause” and the “CG_visibility” buttons. Make sure to reassign the right macros to

$$\text{Lever_wing_x} = \left[\text{Length_fuselage} \cdot \frac{(\text{Leading_edge_wing} - \text{Center_Gravity})}{100} + \frac{\text{Chord_wing}}{4} \right] \cdot \cos(\alpha_plane) + \text{Height_wing} \cdot \sin(\alpha_plane)$$

$$\text{Lever_wing_y} = - \left[\text{Length_fuselage} \cdot \frac{(\text{Leading_edge_wing} - \text{Center_Gravity})}{100} + \frac{\text{Chord_wing}}{4} \right] \cdot \sin(\alpha_plane) + \text{Height_wing} \cdot \cos(\alpha_plane)$$

$$\text{Lever_stabilizer_x} = \left[\text{Length_fuselage} - \frac{3}{4} \cdot \text{Chord_stabilizer} \right] \cdot \cos(\alpha_plane) + \text{Height_stabilizer} \cdot \sin(\alpha_plane)$$

$$\text{Lever_stabilizer_y} = - \left[\text{Length_fuselage} - \frac{3}{4} \cdot \text{Chord_stabilizer} \right] \cdot \sin(\alpha_plane) + \text{Height_stabilizer} \cdot \cos(\alpha_plane)$$

them, macros belonging to the current worksheet. By default, the custom buttons (created by the user from a macro assigned shape) keep the macros from the original worksheet assigned to them.

Implementation:

- O80: “=(Length_fuselage*(Leading_edge_wing-Center_gravity)/100 +Chord_wing/4)*COS(RADIANS(J52))+Height_wing*SIN(RADIANS(J52))”

- O81: “=- (Length_fuselage*(Leading_edge_wing-Center_gravity)/100 +Chord_wing/4)*SIN(RADIANS(J52))+Height_wing*COS(RADIANS(J52))”

- O82: “=(Length_fuselage-3*Chord_stabilizer/4)*COS(RADIANS(J52)) +Height_horizontal_stabilizer*SIN(RADIANS(J52))”

- O83: “=- (Length_fuselage-3*Chord_stabilizer/4)*SIN(RADIANS(J52)) +Height_horizontal_stabilizer*COS(RADIANS(J52))”

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	M	N	O
80	Lever_wing_x		-0.00174497
81	Lever_wing_y		0.049969541
82	Lever_stabilizer_x		0.919550585
83	Lever_stabilizer_y		0.17219675
84			
85			
86			
87			
88			
89			

The force generated moments:

-Using the Cartesian formula to the right (from the previous section) we can identify eight moment components generated by the lift and the drag forces.

$$\vec{M}_O = (y_P - y_O) \cdot \vec{F}_x - (x_P - x_O) \cdot \vec{F}_y$$

- All the forces and movements being in the x-y plane the moments will have z-components exclusively. We can therefore later add the moment effects algebraically.
- Let's group the moment components by the causing force:

$$\text{Moment}_{\text{wing_lift}} = -\text{Lever}_{\text{wing_x}} \cdot \text{Lift}_{\text{wing_y}} + \text{Lever}_{\text{wing_y}} \cdot \text{Lift}_{\text{wing_x}}$$

$$\text{Moment}_{\text{wing_drag}} = -\text{Lever}_{\text{wing_x}} \cdot \text{Drag}_{\text{wing_y}} + \text{Lever}_{\text{wing_y}} \cdot \text{Drag}_{\text{wing_x}}$$

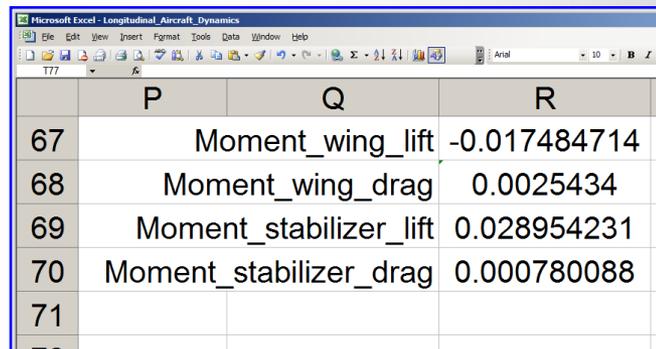
$$\text{Moment}_{\text{stabilizer_lift}} = -\text{Lever}_{\text{stabilizer_x}} \cdot \text{Lift}_{\text{stabilizer_y}} + \text{Lever}_{\text{stabilizer_y}} \cdot \text{Lift}_{\text{stabilizer_x}}$$

$$\text{Moment}_{\text{stabilizer_drag}} = -\text{Lever}_{\text{stabilizer_x}} \cdot \text{Drag}_{\text{stabilizer_y}} + \text{Lever}_{\text{stabilizer_y}} \cdot \text{Drag}_{\text{stabilizer_x}}$$

In aerodynamics, momenta that have the tendency to raise the nose of the airplane are considered positive and momenta which have the tendency to lower the nose of the airplane are negative. Pay attention to signs, I messed it up at first and after seeing weird model behavior I had to come back and fix it!!!

Implementation:

- R67: “=-O80*O68+O81*O67“
- R68: “=-O80*O72+O81*O71“
- R69: “=-O82*O70+O83*O69“
- R70: “=-O82*O74+O83*O73“



	P	Q	R
67	Moment_wing_lift		-0.017484714
68	Moment_wing_drag		0.0025434
69	Moment_stabilizer_lift		0.028954231
70	Moment_stabilizer_drag		0.000780088
71			

Scaling back the pure momenta of the wing and stabilizer (from Xflr5):

- So far we calculated the the momenta generated by the forces of lift and drag applied at the quarter chord points of the wing and the horizontal stabilizer.
- We still need to scale back the c_m (moment coefficient) components of the wing and horizontal stabilizer and add them to the force generated momenta to find the resultant airplane pitching moment.

Several sections ago we extracted the real un-normalized pitching moment :

$$c_m = \frac{m}{q \cdot c^2} = \frac{\frac{M}{Span}}{\frac{\rho \cdot v^2}{2} \cdot c^2} = \frac{\frac{Moment}{Span}}{\frac{Air_density \cdot Speed^2}{2} \cdot Chord^2}$$

$$Moment = c_m \cdot q_d \cdot Chord^2 \cdot Span$$

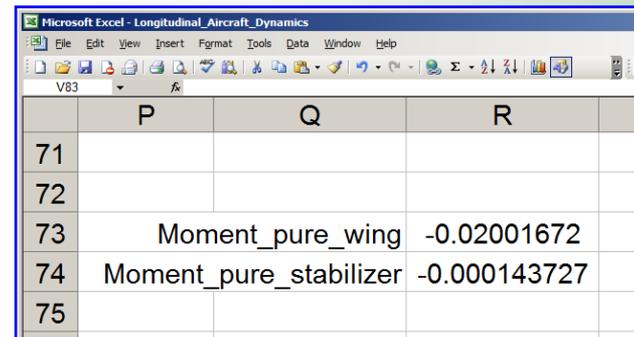
Where q is the dynamic pressure expressed as:

$$q_d = \frac{1}{2} \cdot Air_density \cdot Speed_airplane^2 = \frac{1}{2} \cdot Air_density \cdot (v_{plane_x}^2 + v_{plane_y}^2)$$

- We need to apply the above moment formula for both the wing and the horizontal stabilizer.

Implementation:

- R73: “=V65*O66*Chord_wing^2*Span_wing“
- R74: “=Y65*O66*Chord_stabilizer^2*Span_stabilizer“

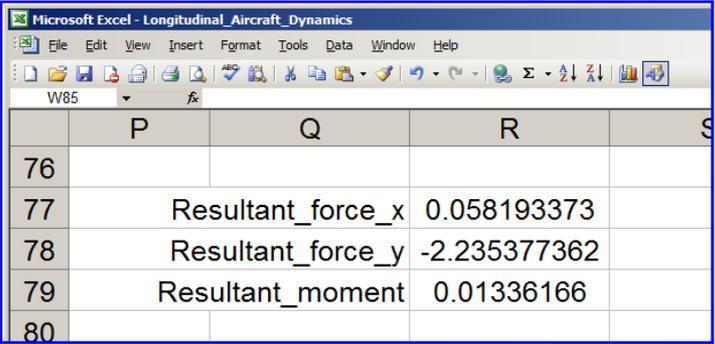


	P	Q	R
71			
72			
73	Moment_pure_wing		-0.02001672
74	Moment_pure_stabilizer		-0.000143727
75			

The balance of forces and momenta around CG:

- Let's calculate the x-y force resultant components and the resultant moment:

- R77: “=O67+O69+O71+O73+O75”
- R78: “=O68+O70+O72+O74+O76+O77”
- R79: “=SUM(R67:R70)+SUM(R73:R74)”



	P	Q	R	S
76				
77		Resultant_force_x	0.058193373	
78		Resultant_force_y	-2.235377362	
79		Resultant_moment	0.01336166	
80				

Timing your work – be slow, use your mind, experiment and play:

- Some decades ago, long before the cell phone era, it was fashionable for the young guys to build electronics. It started with the ham radio craze when everything was based on tubes (I did not catch that period). I caught however the end of the discrete transistor, the end of the TTL and the beginning of the CMOS era.

- Most of people used to follow articles from some geek magazine. And of course whatever they built this way did not work except by accident. This was because they were blindly following a cookbook recipe and most of them did not have a very minimum background in electronics (Ohm's law) or an oscilloscope. Most of them refused to think, trusting the written word. To put it briefly, they were walking blindfolded listening to a tune and hoping to reach a specific destination.

- When you build anything (mechanics, electronics, optics, software, etc) make sure to go one small step at a time and after each step do a thorough testing. Play with your model in all imaginable ways before proceeding with the next step.

- Some people (especially industry bosses) will try to rush you, there is no time, they say. They all do this. And I tell you the truth, there is no bigger waste of time and resources than running through your project, increasing the size of the steps, or even worse, finishing the project and leaving the testing and troubleshooting to the end. The omissions, errors or misunderstandings that slowly creep into the design this way are very hard (if even possible) to find at the end of the project.

A sanity check:

- During building of any of my models I spend most of the time at any stage playing with the model and thinking. Not reading or coding, but playing with parameters, changing angles of perspective and in general having fun with the model. Each new step follows after the “fun” from the previous step starts to “die out”.

- The tutorials are written in a linear fashion and they miss that spirit. You need to be aware of this and balance the content here with a lot of your own experimentation. Don't trust anything you read unless it passes your own experimental tests.

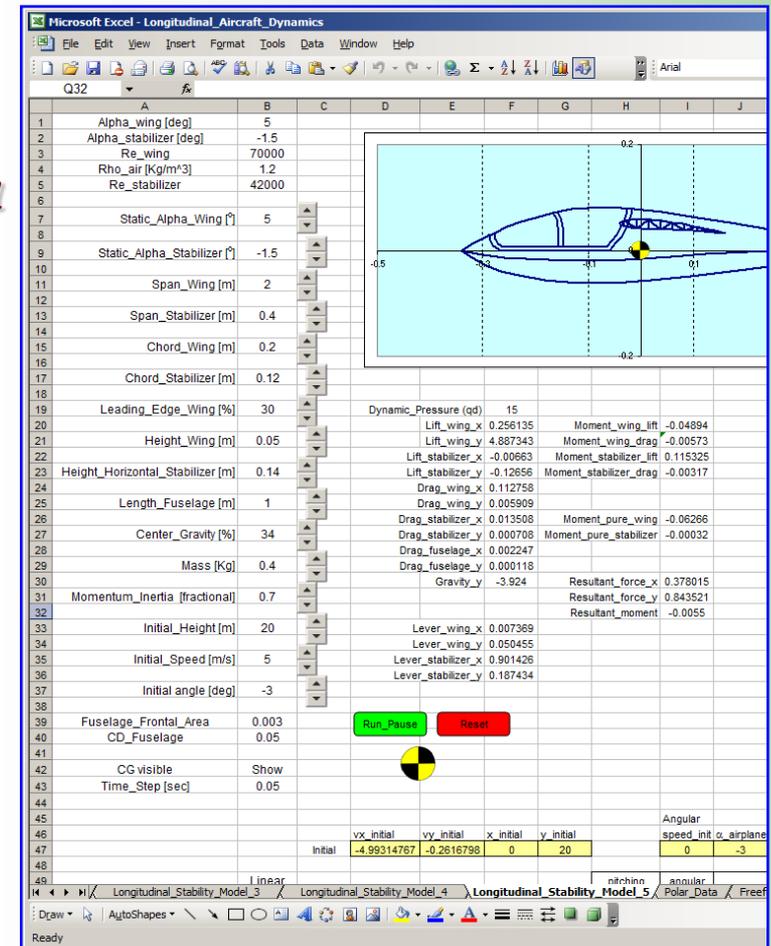
- Let's verify the model we created so far:

- Cut range M66:R83 then select cell D19 and paste. We do this as a provisional step to be able to see the forces and moments while adjusting the input parameters.

- Let's verify the dimensional parameters first. Make sure the chart has a fixed x-scale. Modify one parameter at the time. Try changing the angles of attack of both the wing and the stabilizer, then adjust their chords, the x position of the wing and the height of both the wing and the stab.

- Play with the fuselage length and with the center of gravity. While adjusting CG the plane must shift along the x axis since the origin of the reference is located in the CG.

- After testing the geometrical parameters of the plane let's adjust them while watching the resultant force and moment.



- First, be aware that the wing incidence of a normal plane is around +5 degrees and the incidence of the horizontal stabilizer is slightly negative (-1 or -2 degrees) . Set that, then set the initial speed to 5 m/s and initial launch angle to 0 degrees and hit "Reset". You must now see forces and momenta for plane moving horizontally at a rate of 5 m/s. Later you will experiment with the speed values.
- Now you can adjust the angle of attack and see an proportional variation of the lift. If you increase the main wing angle of attack past 7-10° you might start to see a drop in lift (stall).
- Play with the position of the center of gravity now. Notice that as you bring the CG forward the momentum becomes negative and increases in absolute value. Exactly the opposite must happen as you move the CG backwards. Bring it around the leading edge and start adjusting the angle of attack of the horizontal stabilizer.
- You can see that you can now greatly change the overall moment on the plane between negative and positive values. The negative values are obtained by setting higher positive angles of attack on the horizontal stabilizer. Similarly the larger the negative angle of attack of the stabilizer is the larger the positive resultant moment on the plane will be. Also move the CG a bit forward and try to cancel the higher absolute value negative moment by giving the stabilizer an increased absolute value negative angle of attack. Move it even more now, until you cannot balance it anymore with the stabilizer. Increase the chord or/and the span of the stabilizer and see how you can now balance much more moment change.
- Play a lot with span and chord values of both the wing and the horizontal stabilizer and see how all the forces and moments are affected. Adjust the length of the plane and check for the efficacy of the horizontal stabilizer. Be creative.

To be continued...

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