FS2020 flight model

or how-to make a realistic flight model

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@brief This document explains the dependencies between the flight model parameters. This knowledge should help everybody to produce more realistic flight models.

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Youtube videos

I made Youtube videos of my FS2020 aerobatics airplane flight model modifications See

Extra 330LT X https://youtu.be/Ewfg8hRB8VQ

Pitts S-2S X   https://youtu.be/QzooMQAiDUM

Cap 10 X   https://youtu.be/JVoWW01vaVc

Fix the Extra 330LT flight model, first version

FS2020 has the aerobatics airplanes Cessna 152 Aerobat, CAP 10, Pitts Special S2S and Extra 330LT. The performance of the Extra is impressive: maximum 400°/s roll rate and maximum 3200ft/min climb rate, maximum load factor +/-10g with pilot only and gas only in the middle tank.

The stock Extra 330LT flight model is awful. Setting roll_stability = 0.1 is wrong, a value of 1 is correct. After you roll several turns and you put the stick in neutral position, the Extra rolls a little longer. The real Extra does not show this behavior. Next to the roll bug in all airplanes there are lots of smaller mistakes, e.g. confusing miles per hour with knots per hour.

Before I can fix the Extra 330LT flight model, I have to know the flight envelope of the airplane. The flight envelope is, in narrow sense, the airspeed (x-axis) to load factor (y-axis) diagram. But, "the term is somewhat loosely applied, and can also refer to other measurements such as maneuverability"[1]. I use flight envelope in the broad sense.

Simulator flight envelope

Every airplane has a flight envelope. But the simulator itself has a flight envelope. The modeling of an airplane in the simulator is to "reduce" the performance of the simulator flight envelope to the performance of the airplane flight envelope. Say, the simulator can simulate up to mach 2 airspeed, but little Cessna 152 has a "never exceed speed" of 149 KIAS. You set **max_indicated_speed** to 149.

The same idea applies to maximum load factor. You set **positive_g_limit_flaps_up** , **positive_g_limit_flaps_down** , **negative_g_limit_flaps_up** , **negative_g_limit_flaps_down** and **load_safety_factor** accordingly.

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1   https://en.wikipedia.org/wiki/Flight_envelope

Unfortunately, some simulator flight envelope parameters are hard coded. There is minimum roll inertia that comes from how often control input is read, how often flight model calculation is done and how often display output is produced. The airplane flight envelope can not go beyond this simulator flight envelope.

Best Simulator flight envelope

I have a 4 core AMD 3300X CPU at 4.25GHz, 16GByte RAM at 3200MHz and an Nvidia 1660 Super graphics card. I think this is 750€ cheap do-it-yourself average computer in 2020. Two monitors are connected, one 1920x1200, one 1920x1080.

Best input lag you have with VSYNC on, 20fps and graphics details low.

The parameter controls_reactivity_scalar allows to "tweak" the input lag. A parameter value of 0.1 has a visible influence – control input reaction is sluggish. But I see no difference between a value of 10 and 1. Maybe the simulation is as reactive as possible and can't run faster – even if the parameter tells so.

controls_reactivity_scalar = 4 ; 10 ; Make surfaces 10x more reactive on this plane because we can roll up to 10x faster than with regular planes...

Fix the roll bug

First part of the solution is to find the flight model parameters that have influence on the roll rate. I found **aileron_effectiveness**, **empty_weight_roll_MOI** and **roll_stability**.

aileron_effectiveness = The elevator, aileron and elevator effectiveness parameters are multipliers on the default power of the control surfaces. For example, a value of 1.1 increases the effectiveness by 10 percent. Likewise, a value of 0.9 decreases the effectiveness by 10 percent. A negative number reverses the normal effect of the control. Omission of a parameter results in the default value of 1.0. [2]

empty_weight_roll_MOI = A **moment** of inertia (MOI) defines the mass distribution about an axis of an aircraft. A moment of inertia for a particular axis is increased as mass is increased and/or as the given mass is distributed farther from the axis. This is largely what determines the inertial characteristics of the aircraft.

roll_stability = The pitch, roll and yaw [stability] parameters are multipliers on the default stability (damping effect) about the corresponding axis of the airplane. For example, a value of 1.1 increases the damping by 10%. Likewise, a value of 0.9 decreases the damping by 10%. A negative number results in an unstable characteristic about the axis. A positive damping effect is simply a **moment** in the direction opposite of the rotational velocity. Omission of a parameter will result in the default value of 1.0.

Note: **Moment** is here a mathematical term. The first moment is the mean, the second moment the variance, the third moment the skew, and the fourth moment the kurtosis. Using "a moment" instead of the base parameter brings in the integration behavior. We stop the control input, but the roll continues for some time.

aileron_scaling_table = One of the new, undocumented parameters. My reverse engineering says: This table function gives for x-values, the number before colon (:), a y-value, the number after colon. The most simple function is 0:1. The **aileron_scaling_table** defines aileron to tail (rudder) behavior. A table of 0:2 gives more tail movement for aileron input, a table 0:0.5 gives less tail movement. I assume there is (linear) interpolation between the x,y value pairs. The x-value is aileron angle in degree? or radians? The y-value is a multiplier?

The base parameters for aileron are **aileron_area**, **aileron_up_limit** and **aileron_down_limit**. If I make the area larger and the deflection larger, the aileron movement has more impact on the airplane behavior without the disadvantages of using a moment. Increase the area and/or the

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2   http://www.prepar3d.com/SDKv3/LearningCenter/simobjects/aircraft_configuration_files.html

angle beyond the "real airplane" values has the same effect as making effectiveness larger then one.

aileron_area = 16.3 ; 16.0 ; Elevator area (SQUARE FEET)
aileron_up_limit = 25 ; 30 ; Aileron max deflection angle (DEGREES)
aileron_down_limit = 25 ; 30 ; Aileron max deflection down angle (absolute value) (DEGREES)
aileron_effectiveness = 3 ; 2
roll_stability = 1 ; 0.25
empty_weight_roll_MOI = 48 ; 560 ; Empty roll moment of inertia, Jzz (SLUG SQ FEET)
aileron_scaling_table = 0:0.5 ; 0:1

Note: The first number is my value and it is used by the simulator. The second number is the Asobo "guess" in FS2020 version 1.9.5.0.

The first three numbers are from the technical data of the airplane. The other numbers are "tuned". I run many experiments to get a fast and precise roll behavior. As an old instrumentation and control engineer I call **aileron_area**, **aileron_up_limit**, **aileron_down_limit** and **aileron_effectiveness** the P-term. P is the proportional part in the PID controller. The parameters **roll_stability** and **empty_weight_roll_MOI** are the I-term, the integration part in the PID controller.

Note: instrumentation and control is an old engineering trade. We use words sometimes in a funny way. The PID controller today is a digital filter implemented as some lines of source code in a computer program. I will not give a PID tutorial. But one important fact is, the P-term controls the "hard" or "direct" behavior of the system and the I-term controls the "soft" or "delayed" behavior of the system.

For measurement of roll rate I created a video. Just enter WIN+ALT+R to record. Then I used "Windows Media Player" for playback and looked at the times between one roll and the next. Increasing airspeed gives a shorter time for every roll. I was satisfied with tuning after one roll at 180 KIAS needed a time span of one second.

Moments of Inertia

If all mass of the airplane is in the CG, there would be no inertia. Because the mass is distributed through the airplane, these masses oppose the change done by aileron, elevator or rudder movement. The CAP 10C POH shows the calculation of moments of inertia (MOI).

The following table from the POH shows the formulas to calculate balance and moments.

6.4.3 Loading category A

	Weight (kg)	Lever arm (m)	Moment (m.kg)
Empty weight	a1	b1	c1 = a1 x b1
Pilot	a2	0,55 to 0,65	c2 = a2 x b2
Passenger	a3	0,55 to 0,65	c3 = a3 x b3
Usable fuel FWD tank	a4	- 0,243	c4 = a4 x b4
Totals weight and moment	A = Σan	B = C/A	C = Σcn
Balance in **kg**, **m** and **m.kg**	(B/1.5) x 100 =		%

Balance must be between 20 % and 26 % (category A).

Maximum weight: 780 kg (1 720 lb)

This table from the POH gives an example of the calculation.

	Weight kg	Lever arm m	Moment m.kg
Empty weight	550	0.297	163.4
Pilot	83	0.6	49.8
Passenger	0	0.6	0
Usable fuel FWD tank	40	- 0.243	- 9.72
Totals weight and moment	673	0.302	203,4
Balance (% of MAC) in **kg**, **m** and **m.kg**	(B/1.5) x 100 =		20.2 %

There are rough estimates formulas for the simulator MOIs.[3] The formulas are:

empty_weight_pitch_moi = empty_weight * fuselage_length^2 / 810

empty_weight_roll_moi = empty_weight * wing_span^2 / 1870

empty_weight_yaw_moi = empty_weight * avg(fuselage_length, wing_span)^2 / 770

The function avg() is the average of the givven numbers. avg(a, b) = (a + b) / 2.

empty_weight_coupled_moi = 10 ; a constant

The tiny Pitts S-2S has very good MOI numbers.

SG-38 MOI

empty_weight = 244 ; lb
fuselage_length = 20.6 ; ft
wing_span = 34.2 ; ft

empty_weight_pitch_moi = 128
empty_weight_roll_moi = 153
empty_weight_yaw_moi = 238
empty_weight_coupled_moi = 10

Extra 330LT MOI

empty_weight = 1308 ; lb
wing_span = 26.3 ; ft
fuselage_length = 23 ; ft

empty_weight_pitch_moi = 854
empty_weight_roll_moi = 484
empty_weight_yaw_moi = 1032
empty_weight_coupled_moi = 10

Note: For fast and precise roll behavior I changed the **empty_weight_roll_moi** to 100.

Attention: Changing **roll_stability** to a tenth **DOES NOT** have the same effect as changing **MOI** to a tenth.

Pitts S-2S MOI

empty_weight = 1150 ; lb
wing_span = 20 ; ft
fuselage_length = 17 ; ft

empty_weight_pitch_moi = 410
empty_weight_roll_moi = 246

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3   http://www.prepar3d.com/SDKv3/LearningCenter/simobjects/aircraft_configuration_files.html

empty_weight_yaw_moi = 511
empty_weight_coupled_moi = 10

Note: For fast and precise roll behavior I changed the **empty_weight_roll_moi** to 100.

CAP 10C MOI

empty_weight = 1190 ; lb
wing_span = 26.44 ; ft
fuselage_length = 23 ; ft

empty_weight_pitch_moi = 777
empty_weight_roll_moi = 445
empty_weight_yaw_moi = 944
empty_weight_coupled_moi = 10

Note: For fast and precise roll behavior I changed the **empty_weight_roll_moi** to 100.

Tune the loop behavior

For the sake of discussion I change the pitch behavior of the flight model. This time we have the P-term parameters **elevator_area**, **elevator_up_limit**, **elevator_down_limit** and **elevator_effectiveness.** The I-term parameter or integral parameters is **empty_weight_pitch_moi** and **pitch_stability**.

I am not satisfied with the elevator reaction on my control input. Using only technical data and no I-term, the Extra 330LT flies like a lame duck. The Asobo "guess" for flight model is **pitch_stability** = 0.25. This gives a very "woolly" flight model.

Therefore I change the system into a PI-controller. I give more proportional "leverage" between control input and airplane movement, but I also add same integral "softness" to avoid unnecessary stall after pulling the stick too much, too fast.

Note: Another funny thing is that for an instrumentation and control engineer everything is a system or a sub-system or a sub-sub-system. And he or she has at least 1001 different definitions for system. Our PI-system for elevator control is embedded in the next larger system, the feedback loop between man (you) and machine (the flight simulator). Itself it is build out of two parts (sub-systems), the P-controller and the I-controller.

elevator_area = 13.8 ; 13 ; Elevator area (SQUARE FEET)
elevator_up_limit = 25 ; 26 ; Elevator max deflection up angle (DEGREES)
elevator_down_limit = 25 ; 26 ; Elevator max deflection down angle (absolute value) (DEGREES)
elevator_trim_limit = 35 ; 15 ; Elevator trim max angle (absolute value) (DEGREES)
elevator_effectiveness = 1.22 ; 1
pitch_stability = 0.82 ; 0.25
empty_weight_pitch_MOI = 854 ; 1509 ; Empty pitch moment of inertia, Jxx (SLUG SQ FEET)

The P-term is "scaled" by 1.22 and the I-term is "scaled" by 1.22 from the "do nothing" value of 1, even if this 1.22 is in the denominator. I did not "amplify" the elevator trim from technical data value. But you can. Trim is not very important in an aerobatics airplane...

Dull the rudder

The Asobo "guess" for rudder control was again a stability value of 0.25. I am more happy with no I-term. The rudder in a real Extra has little impact – this I saw in a Youtube video. Therefore I "dimmed" effectiveness. Here are the P-term and I-term parameter for rudder.

rudder_area = 5.6 ; 7 ; Elevator area (SQUARE FEET)
rudder_limit = 30 ; Rudder max deflection angle (absolute value) (DEGREES)
**rudder_effectiveness** = 0.25 ; 1

yaw_stability = 1 ; 0.25
empty_weight_yaw_MOI = 1032 ; 1883 ; Empty yaw moment of inertia, Jyy (SLUG SQ FEET)

There is **rudder_trim_limit**, but I don't use this parameter.

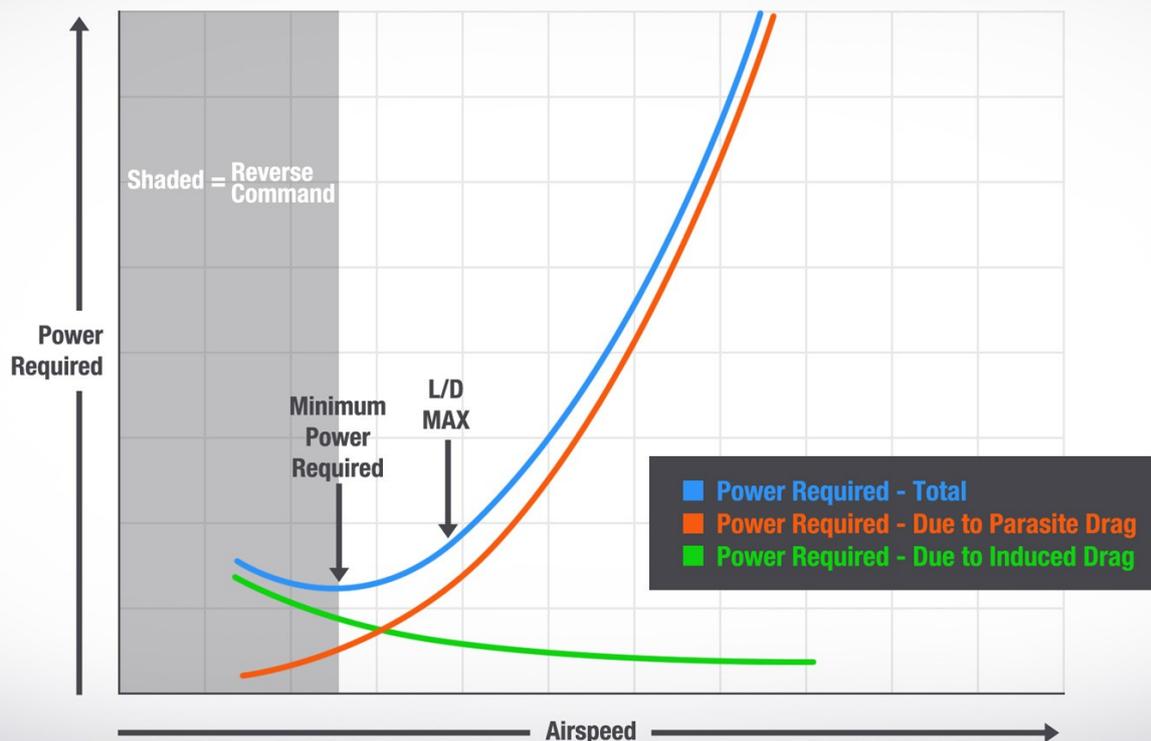# Back side of the power curve

See https://www.aopa.org/news-and-media/all-news/2013/november/pilot/proficiency-behind-the-power-curve and https://www.boldmethod.com/learn-to-fly/maneuvers/private-slow-flight-why-do-i/

One glance at the power curve immediately tells you that it takes as much power to fly very slowly [at stall speed] (A) as it does to fly at cruise speed (B)
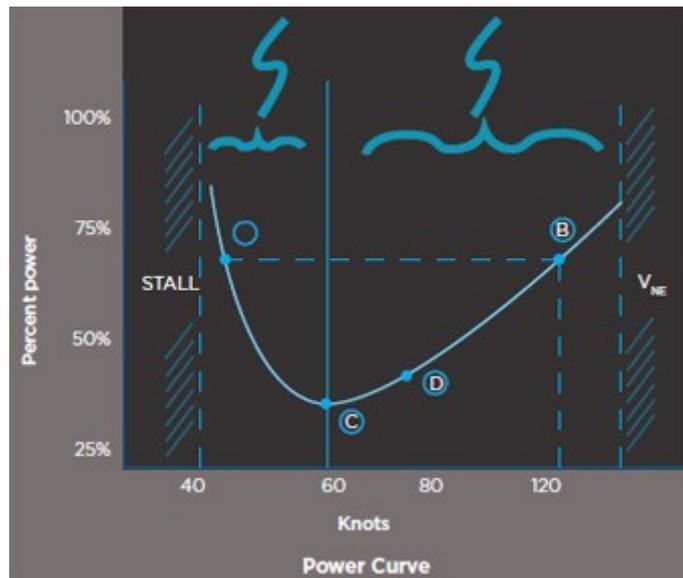
"**cruise_lift_scalar** = The cruise_lift_scalar parameter is a multiplier on the coefficient of lift at zero angle of attack Cruise lift in this context refers to the lift at relatively small angles of attack, which is typical for an airplane in a cruise condition. This scaling is decreased linearly as angle of attack moves toward the critical (stall) angle of attack, which prevents destabilizing low speed and stall characteristics at high angles of attack. Modify this value to set the angle of attack (and thus pitch) for a cruise condition. A negative value is not advised, as this will result in extremely unnatural flight characteristics. Omission of this parameter results in the default value of 1.0.

Drag is the aerodynamic force that determines the aircraft speed and acceleration. There are two basic types of drag that the user can adjust here.

parasite_drag_scalar = Parasitic drag is composed of two basic elements: form drag, which results from the interference of streamlined airflow, and skin friction. Parasite drag increases as airspeed increases.

induced_drag_scalar = Induced drag results from the production of lift. Induced drag increases as angle of attack increases.

The parasite_drag_scalar and induced_drag_scalar parameters are multipliers on the two respective drag coefficients. For example, a value of 1.1 increases the respective drag component by 10 percent. A value of 0.9 decreases the drag by 10 Percent. Negative values are not advised, as extremely unnatural flight characteristics will result. The default values are 1.0." [4]

flap_induced_drag_scalar = New parameter in FS2020.

Polar curve
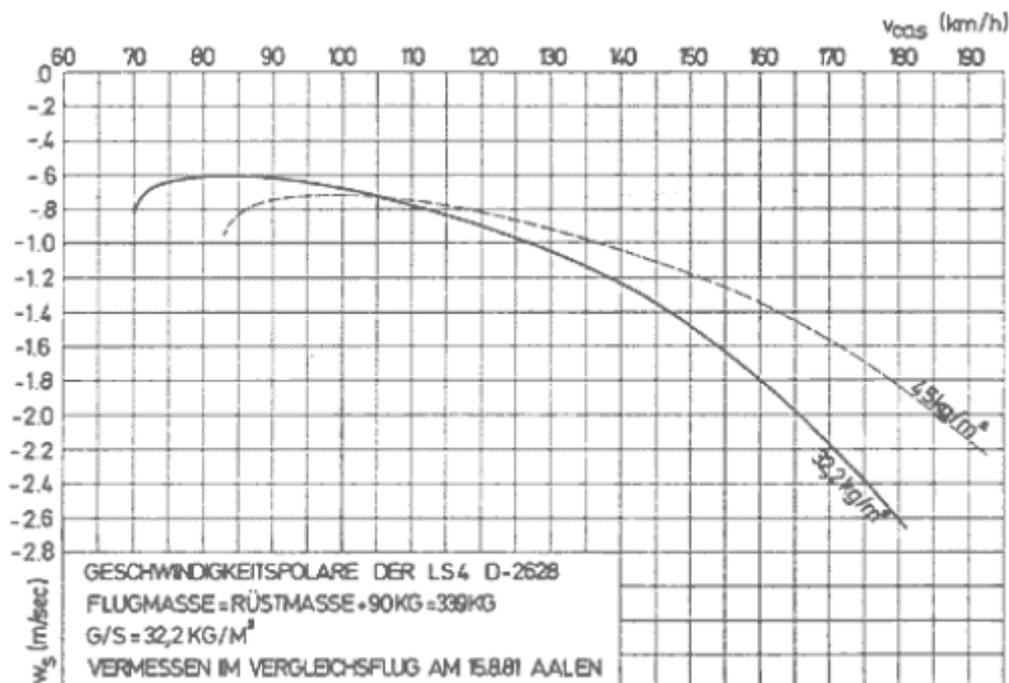
Left to right is the airspeed, top to down is the vertical speed. We can see that there is a "best" vertical speed at 84 km/h for the solid line. The drag increases (vertical speed worsens) if you go faster or slower.

A sailplane has no engine, but we can use the drag_scalars to implement the polar curve. In the polar curve above we find for wing load 32.2kg/m^2 a stall speed of 70 km/h and a vertical speed of 0.8m/s (37.8 kts, 157 fpm). Cruise speed is 160 km/h and -1.8 m/s (86.4 kts, 354 fpm).

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4   http://www.prepar3d.com/SDKv3/LearningCenter/simobjects/aircraft_configuration_files.html

Left-Turning Tendencies

This is FS2020 version 1.10.8.0 behavior which is not realistic:

p_factor_on_yaw = Effective only if airplane has ground contact and lift is less then weight. Affects 3-point position, tail wheel on the ground.

gyro_precession_on_yaw = Effective only if airplane has ground contact and lift is less then weight. Affects 2-point position, tail wheel off the ground.

hi_alpha_on_yaw = ?

Real pilots write: BremyG: "This is a funny one in the sim. In the sim, left-turning tendencies seem to be modeled and very effective when the airplane is touching the ground, but seem to disappear at liftoff (which is when you'd expect p-factor to increase as angle of attack increases). There's almost no need for rudder in the air in the sim, because adverse yaw doesn't seem to be modeled either."

FutureFlyer828: "As a real world pilot, it is not correct. When you take off in a 172, you hold right rudder… and in the climb you hold right rudder."

Tacot37: "From the first meters of taxiing on take-off, the plane goes to the left, it is necessary to counter the direction to stay on the runway axis: this is mainly due to the helical breath of the propeller.

Then when moving to the 2-point position (two wheels) the gyroscopic torque of the propeller and the engine the aircraft tends to swerve to the left which must be countered in the steering.

It should be noted that unlike the tricycle landing gear, the [Cap10] aircraft is unstable in direction (a swerve tends to be amplified if the pilot does not react!)

After takeoff, during the climb, as the speed is low, it is necessary to maintain pressure on the right on the rudder to maintain symmetrical flight, otherwise the ball (slip indicator) goes to the right. Then when the speed increases we can release the rudder. Normally the designer of the aircraft has provided a tail wedge so that the steering is in neutral at cruising speed. Above the cruising speed it is necessary to put the direction to the left to maintain a symmetrical flight (otherwise the ball goes to the left)."

torque_on_roll = Engine power dependent roll effect.

hi_alpha_on_roll =

gyro_precession_on_roll =

See https://www.boldmethod.com/learn-to-fly/aerodynamics/why-you-need-right-rudder-on-takeoff-to-stay-on-the-centerline/

Look at speeds

The POH uses some or all of the following speeds:

Vso = stalling speed in a landing configuration at maximum gross weight.

Vx = greatest altitude gain over a set distance (best angle of climb).

Vy = gives you the greatest altitude gain over time (best rate of climb).

Best glide = provides the best forward distance in an engine failure.

Va = maneuvering speed. This is the speed above which it is unwise to make full application of any single flight control.

Vne = maximum airspeed in smooth air.

The FSX speeds are:

full_flaps_stall_speed = Vso = Stall speed of the aircraft in a dirty (flaps full down) configuration at standard sea level conditions, (Knots True Airspeed, KTAS). I assume **full_flaps_stall_speed** is 90% of **flaps_up_stall_speed.**

flaps_up_stall_speed = Vs = Stall speed of the aircraft in a clean (flaps up) configuration at standard sea level conditions, (Knots True Airspeed, KTAS).

cruise_speed = Va = Typical cruise speed of the aircraft in a clean (flaps up) configuration at a typical cruise altitude, (Knots True Airspeed, KTAS).

max_indicated_speed = Vne = Maximum design indicated airspeed. Also referred to as Never Exceed Speed or Red Line of the aircraft, (Knots Indicated Airspeed).

The additional FS2020 speeds are:

rotation_speed_min = Min speed required (Kts)

max_flaps_extended = Vfe

climb_speed = Vy = Climb speed (Kts)

best_angle_climb_speed = Vx = Best angle climb speed (Kts)

best_glide = Best Glide (Kts)

takeoff_speed = Vfto (Vto) = Takeoff Speed (Kts)

approach_speed = Approach speed (Kts)

normal_operating_speed = Vo

airspeed_indicator_max =

Summary

We can call the simulator parameters an "overdetermined system". There are more parameters as there are "unknowns". We can call the elevator P-term an "unknown" and we have the **elevator_area** and **elevator_*_limit** parameters to set this P-term value. If we want more P-term "unknown" value, we can increase the first parameter, we can increase the second parameter or we can increase both parameters.

In an overdetermined system different parameter values can result in the same system behavior.

In my opinion the simulator flight envelope can barely meet the Extra 330LT flight envelope.

Pitts S-2S flight model

The maximum roll rate of the S-2S is "only" 240°/s. It should be easy to set the simulator parameters. But the short wings or other differences (biplane?) between the Extra and the Pitts made a modification of the Extra solution necessary. This time I use **aileron_effectiveness** larger then one. I think ***_effectiveness** is a P-term.

The parameters are:

empty_weight_pitch_MOI = 410 ; 650 ; Empty pitch moment of inertia, Jxx (SLUG SQ FEET)
empty_weight_roll_MOI = 25 ; 246 ; 626 ; Empty roll moment of inertia, Jzz (SLUG SQ FEET)
empty_weight_yaw_MOI = 511 ; 1183 ; Empty yaw moment of inertia, Jyy (SLUG SQ FEET)
empty_weight_coupled_MOI = 10 ; Empty transverse moment of inertia, Jyz (SLUG SQ FEET)
elevator_area = 12 ; Elevator area (SQUARE FEET)
aileron_area = 8 ; Elevator area (SQUARE FEET)
rudder_area = 12 ; Elevator area (SQUARE FEET)
elevator_up_limit = 25 ; Elevator max deflection up angle (DEGREES)
elevator_down_limit = 25 ; Elevator max deflection down angle (absolute value) (DEGREES)
aileron_up_limit = 25 ; Aileron max deflection angle (DEGREES)
aileron_down_limit = 25 ; Aileron max deflection down angle (absolute value) (DEGREES)
rudder_limit = 30 ; Rudder max deflection angle (absolute value) (DEGREES)

elevator_trim_limit = 20 ; Elevator trim max angle (absolute value) (DEGREES)
controls_reactivity_scalar = 4 ; 10 ; Make surfaces 10x more reactive on this plane because we can roll up to 10x faster than with regular planes…
elevator_effectiveness = 1
aileron_effectiveness = 7 ; 2
rudder_effectiveness = 1
pitch_stability = 1 ; 0.1
roll_stability = 1 ; 0.1
yaw_stability = 1 ; 0.1

I do not understand why the Asobo "guess" of the flight model uses a larger gain in ***_stability** then in the Extra. I always work after the maxim: "nichts ist praktischer als eine funktionierende Theorie (nothing is more practical than a working theory)". I know tinkering is necessary, but as engineer I like to minimize it.

CAP 10C flight model

The maximum roll rate of the CAP 10C is 320°/s.

The parameters are:

elevator_area = 58.4 ; 15 ; Elevator area (SQUARE FEET)
aileron_area = 62.5 ; 8 ; Elevator area (SQUARE FEET)
rudder_area = 12 ; Elevator area (SQUARE FEET)
elevator_up_limit = 50 ; 25 ; Elevator max deflection up angle (DEGREES)
elevator_down_limit = 50 ; 25 ; Elevator max deflection down angle (absolute value) (DEGREES)
aileron_up_limit = 50 ; 25 ; Aileron max deflection angle (DEGREES)
aileron_down_limit = 50 ; 25 ; Aileron max deflection down angle (absolute value) (DEGREES)
rudder_limit = 30 ; Rudder max deflection angle (absolute value) (DEGREES)
elevator_trim_limit = 20 ; Elevator trim max angle (absolute value) (DEGREES)
elevator_effectiveness = 1
aileron_effectiveness = 4 ; 2
rudder_effectiveness = 1
pitch_stability = 1 ; 0.1
roll_stability = 1 ; 0.1
yaw_stability = 1 ; 0.1
controls_reactivity_scalar = 20 ; 10 ; Make surfaces 10x more reactive on this plane because we can roll up to 10x faster than with regular planes...

I do not understand why the Asobo "guess" of the flight model uses a larger gain in ***_stability** then in the Extra. I always work after the maxim: "nichts ist praktischer als eine funktionierende Theorie (nothing is more practical than a working theory)". I know tinkering is necessary, but as engineer I like to minimize it.

Extra 330LT technical data

The airplane technical data like wingspan, wing-area are simulation parameters. The "numerical integration beast" that is the heart of the flight model does not use these parameters directly. But it is convenient to be able to enter Pilot's Operating Handbook (POH) parameters and the flight model converts these data sheet values into internal values. I discuss the technical data values as they appear in the POH.

The coordinate origin of the Asobo Extra330LT is the wing edge. The longitudinal coordinates are positive in direction nose and negative in direction tail. The CG as 25% MAC location is therefore a negative number.

Wing span goes into point.4 lateral and point.5 lateral. The wings stretch left and right from the CG.

point.4 = 2, -0.8, -13.15, -0.5, ...
point.5 = 2, -0.8, 13.15, -0.5, ...

Wheel base and wheel track go into point.0 to point.2. The difference between point.0 longitudinal and point.1, point.2 longitudinal is the wheel base. The difference between point.1 lateral and point.2 lateral is the wheel track.

point.0 = 1, -14.9,   0,   -1.725, ...
point.1 = 1,   2,   -2.92, -4.13, ...
point.2 = 1,   2,   2.92, -4.13, …

fuselage_length = 23 ; -1 ; Nose to tail (FEET)
static_cg_height = 3.75 ; feet, altitude of CG when at rest on the ground – from 3-view diagram

1.3.3 Wing

wing_span = 26.3 ; Wing span b (FEET)
wing_area = 116.7 ; Wing area S (SQUARE FEET)
aileron_area = 16.3 ; (SQUARE FEET) – area of both ailerons
aileron_up_limit = 25 ; Aileron max deflection angle (DEGREES)
aileron_down_limit = 25 ; Aileron max deflection down angle (absolute value) (DEGREES)

Note: The Extra 330LX POH says "Aileron deflection up 30°, down 20°". The Extra 330LX and 330SC POH say +-25°. This makes more sense for me.

1.3.4 Horizontal tail

htail_span = 10.5 ; Horizontal tail span (FEET)
htail_area = 27.5 ; Horizontal tail area (SQUARE FEET)

1.3.5 Elevator

elevator_area = 7.8 ; Elevator area (SQUARE FEET)
elevator_up_limit = 25 ; Elevator max deflection up angle (DEGREES)
elevator_down_limit = 25 ; Elevator max deflection down angle (absolute value) (DEGREES)
elevator_trim_limit = 35 ; Elevator trim max angle (absolute value) (DEGREES) – no up, down parameter

1.3.6 Vertical tail

vtail_area = 14.9 ; Vertical tail area (SQUARE FEET)

1.3.7 Rudder

rudder_area = 5.6 ; Elevator area (SQUARE FEET)
rudder_limit = 30 ; Rudder max deflection angle (absolute value) (DEGREES)

2.2 Air speed (IAS)

cruise_speed = 160   ; Va   maneuvering speed

max_indicated_speed = 221   ; Vne   never exceed speed

normal_operating_speed = 160   ; Vno   maximum structural cruising speed

2.4.2 Engine Limitations

max_rated_rpm = 2700 ; Max rated RPM

2.14.3 Instrument Markings

The color markings are green for 65 to 160 KIAS, yellow for 160 to 221 KIAS and red for 221 KIAS.

[AIRSPEED]
green_start = 65
green_end = 160
yellow_start = 160
yellow_end = 221
red_start = 221
red_end = 222

The engine RPM markings are green for 700 to 2700 RPM and red for 2700 RPM.

[RPM]
green_start = 700
green_end = 2700
yellow_start = 0
yellow_end = 0
red_start = 2700
red_end = 2701

2.6 Weight limits

max_gross_weight = 1808 ; (LBS) - for Acrobatic category I

3.1 Airspeeds for emergency operation

best_glide = 85 ; Best Glide (Kts)

Note: Glide angle is 1:6.2.

4.0.1 Airspeeds for normal operation

best_angle_climb_speed = 70   ; Vx   best angle-of-climb speed

climb_speed = 88   ; Vy   best rate-of-climb speed

rotation_speed_min = 65   ; Start, rotate speed

approach_speed = 90   ; Landing, approach (final = 79, go-around = 102)

4.5.2 Take-off

takeoff_speed = 68 ; Takeoff Speed (Kts)

5.4 Stall speed

full_flaps_stall_speed = 60   ; Vs   stalling speed or minimum steady flight speed
flaps_up_stall_speed = 60   ; Vs   stalling speed or minimum steady flight speed

Note: The Extra has no flaps.

Extra 330LT weight and balance

Every airpalne has a 3D model coordinate system origin and a flight model coordinate system origin. Both origins can be the same. The parameter **reference_datum_position** gives the difference between the two origins.

reference_datum_position = 0, 0, 0 ; Position of reference datum relative to FS(0,0,0) (FEET), z, x, y

The FS2020 coordinate system has the origin "somewhere" in the airplane. I use the distance between nose and origin to mark the origin in the airplane view. The nose is 7.4 ft away from as **point.3** tells us.

point.3 = 17, 7.4, 0,   0.4, ... ; nose

This drawing shows the firewall, the POH datum line.

Reference Firewall (plane)
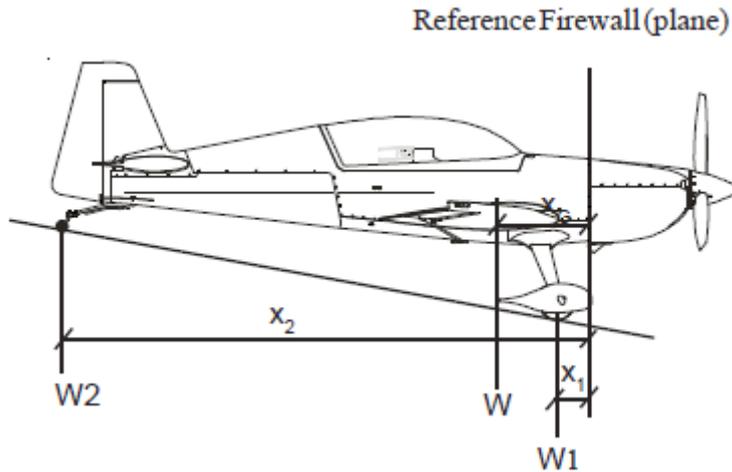
This is the 3-view drawing of the Extra 330LT. I use the Extra length of 23 ft to determine the scale of the airplane drawing and place the simulator origin 6.5 ft from the nose as green dot in the drawing:
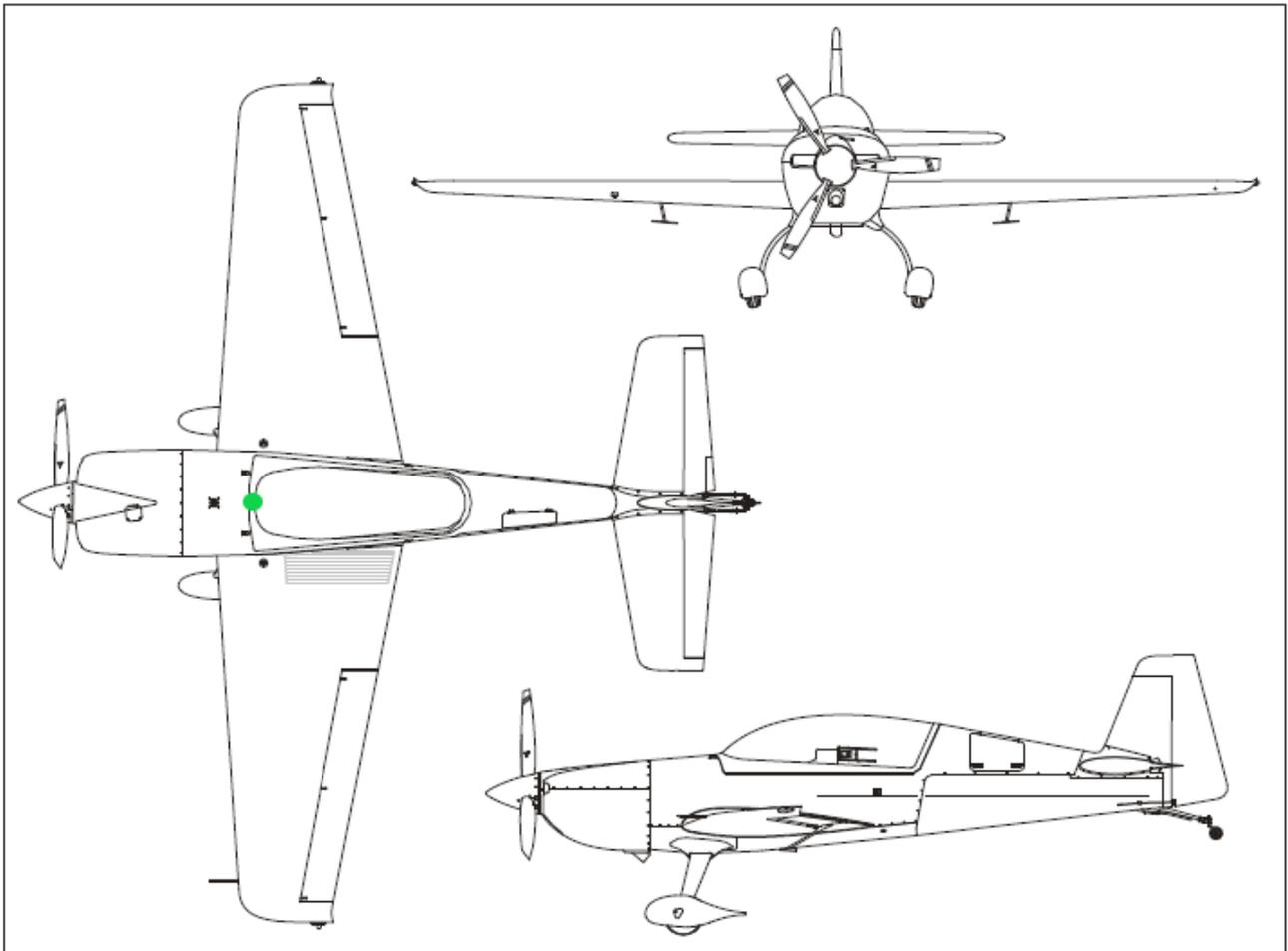
The firewall is 5 ft away from the nose or 2.4 ft away from flight model origin.

6.2 Aircraft weighing procedure

Datum line for weight arms x is the fire wall.

Note: The firewall is **NOT** the flight model coordinate origin.

6.4 Loading weights and moments

Fuel acro & center tank arm = 28 .. 30 cm = 11 .. 12 in = 0.9 .. 1 ft [1.4 ft]

Fuel wing tank = 83 cm = 32.7 in = 2.7 ft [-0.3 ft]

Copilot front seat arm = 98 cm = 38.4 in = 3.2 ft [-0.8 ft]

Pilot rear seat arm = 207cm = 81.5 in = 6.8 ft [-4.4 ft]

Baggage compartment arm = 331 cm = 130.3 in = 10.9 ft [-8.5 ft]

The numbers in [ ] are relative to the flight model origin.

The pilot location is **station_load.0**, the copilot location **station_load.1**. Because I only simulate aerobatics flight, there is no copilot, baggage or fuel in wing tanks.

station_load.0 = 170, -4.4, 0, 0, Pilot ; mass lb, longitudinal ft, lateral ft, vertical ft, name
station_load.1 = 170, -0.8, 0, 0, Copilot ; mass lb, longitudinal ft, lateral ft, vertical ft, name

2.4.1 Fuel

Total fuel capacity for acrobatics in acro & center tank = 18.2 US gal

Usable fuel capacity for acrobatic in acro & center tank = 17.7 US gal

Every tank has the parameters: Tank position (z longitudinal, x lateral, y vertical) (FEET), total fuel capacity (GALLONS), unusable fuel capacity (GALLONS)

LeftMain = 0, 0, 0, 0, 0 ; -1.5, -4.6, 0, 20.1, 1.35
RightMain = 0, 0, 0, 0, 0 ; -1.5, 4.6, 0, 20.1, 1.35
Center1 = 1.4, 0, 0, 18.2, 0.5 ; 0, 0, 0, 10, 0.5

The center of gravity (CG) of an aircraft is the point over which the aircraft would balance.

The thin airfoil theory says: On a symmetric airfoil, the center of pressure and aerodynamic center are coincident and lie exactly one quarter of the chord behind the leading edge. On a cambered airfoil, the aerodynamic center lies exactly one quarter of the chord behind the leading edge.[5]

The center of gravity (CG) of an aircraft is the point over which the aircraft would balance. The "quarter of the chord" point is the 25% MAC in FS2020. If CG is at 25% MAC, the flight behavior is fine.

The location of empty_weight_cg_position can be computed. Another approach is to set **empty_weight** to zero, add some **station_load.x** entries with zero and negative longitudinal location and use the "Gewicht und Gleichgewicht" tab. Sooner or later you find that -0.24 is the correct longitudinal to balance the airplane at the 25% MAC position.

empty_weight_CG_position = 0.24, 0, 0 ; 0.85, 0, 0 ; Position of airplane empty weight CG relative to reference datum (FEET), z, x, y

Note: The Asobo longitudinal positions are wrong. The nose position is positive, the tail position is negative. Therefore the pilot position is negativeis The airplane balances at 25% MAC

I want that the airplane "lies" in the air like a boat "lies" on water. The airplane waterline is exactly this. The **wing_incidence** and **htail_incidence** parameter control this in a real airplane. For stable flight, the **wing_incidence** and **htail_incidence** are different, the difference is typically 3°, but less for an aerobatics airplane. The **wing_incidence** is NOT used by the simulation. You can give it a value, but the used value is always zero. The Extra 330LT has

wing_incidence = 0 ; Wing incidence (DEGREES)
htail_incidence = 2 ; Horizontal tail incidence (DEGREES)

The elevator trim determines how the airplane "lies" in the air in level flight. You can set the elevator trim which the airplane uses at the start of the flight.

elevator_trim_neutral = 9 ; 4 ; Elevator trim default angle (absolute value) (DEGREES)

Up to now I touched only the most important flight behavior model parameters. I want to make one important point: In many cases you can change one aspect of the flight behavior model with different parameters. For example: If you want to have another "default speed", the speed without control input, you can change the **empty_weight_cg_position**, change the **htail_incidence** or change the **lift_scalar** and **drag_scalar** parameters.

BUT the different changes are not equal. They MAY give you the same new default speed, but the airplane behavior will be different. A very simple example is how the airplane rests on the ground. The current ASK 23 CG let the airplane rest on the nose gear and main gear. If you change the **empty_weight_cg_position** for a new default speed, the ASK 23 may rest on the main gear and tail gear. If you change the **htail_incidence** for a new default speed, you will not have the "how the airplane rests" side effect, but you will have other side effects, e.g. how the airplane behaves in a loop.

These side effects or dependencies between flight behavior model parameters make creating a good model within the limitations of the simulator an art. I am new in MSFS 2020 modeling, but I have done modeling for 30 years in other areas, e.g. electronic circuit simulation. See https://www.highfrequencyelectronics.com/Archives/Nov13/1311_HFE_squegging.pdf

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5   https://en.wikipedia.org/wiki/Airfoil#Thin_airfoil_theory

Pitts S-2S technical data

I found no Aviat Pitts S-2S POH, but an S-2B POH. The differences between both airplanes are small. In the top picture[6] the S-2S is the left airplane, in the bottom picture the right one.

6   http://www.flugzeuglexikon.com/ILA%20-%20Luftfahrtausstellung/Historische%20Flugzeuge/Pitts%20S-
    2S%20und%20Pitts%20S-2B%20-%20Doppeldecker/pitts%20s-2s%20und%20pitts%20s-2b%20-
    %20doppeldecker.html

The POH gives a checklist for normal landing.

1. airspeed = 83 KIAS
2. trim = adjust
3. touchdown = tail wheel first
4. elevator control = full back (up elevator)
5. braking = minimum required

The POH gives another checklist for emergency landing without engine power.

1. airspeed = 83 KIAS
2. mixture = idle cut-off
3. fuel selector valve = off
4. ignition switch = off
5. canopy = jettison (at pilot's option)
6. master switch = off when landing is assured
7. touchdown = tail wheel first
8. brakes = apply as needed but control the aircraft

I use the "aerobatic flight" technical data from the POH. Normally that is less tank capacity and less maximum take off weight (MTOW).

For aerobatics flight only gas in the main (center) tank is allowed.

center1 = -1, 0, -0.86, 24, 1 ; -1, 0, -0.86, 20, 1
center2 = 0, 0, 0, 0, 0 ; 0, 0, -0.86, 15, 1

Section 1

wing_span = 20 ; Wing span b (FEET)

fuselage_length = 17.8 ; Nose to tail (FEET)

max_gross_weight = 1625 ; Empty weight, (LBS)

empty_weight = 1150 ; Empty weight, (LBS)

Section 2

The never exceed speed (Vne) is 184 KIAS, maneuvering speed (Va) is 134 KIAS. Asobo entered the miles per hour numbers, not the knots per hour numbers.

cruise_speed = 134 ; 154 ; Knots True (KTAS)
max_indicated_speed = 184 ; 212 ; Red line (KIAS)
normal_operating_speed = 134 ; 154
airspeed_indicator_max = 200 ; 250

The color markings are green for 53 to 134 KIAS, yellow for 134 to 183 KIAS and red for 184 KIAS.

[AIRSPEED]
green_start = 53 ; 50
green_end = 134
yellow_start = 134
yellow_end = 183 ; 176
red_start = 183 ; 176
red_end = 184 ; 178

The **rotation_speed_min** is minimum speed.

rotation_speed_min = 53 ; 55 ; Min speed required (Kts)

The POH flight load factor limits in the aerobatics category are +6/-3 G. I reduce the **load_safety_factor** to 10%.

positive_g_limit_flaps_up = 6 ; 4 ; Flap positive load limit when up.
negative_g_limit_flaps_up = -3 ; -3.2 ; Flap negative load limit when up.
positive_g_limit_flaps_down = 6 ; 2.8 ; Flap positive load limit when down.
negative_g_limit_flaps_down = -3 ; -2.4 ; Flap negative load limit when down.
load_safety_factor = 1.1 ; 1.5

The engine RPM markings are green for 500 to 2700 RPM and red for 2700 RPM.

[RPM]
green_start = 500 ; 0
green_end = 2699 ; 0
yellow_start = 0
yellow_end = 0
red_start = 2700 ; 0
red_end = 2701 ; 0

Section 4

The POH en route climb, normal is 104 KIAS, best angle speed is 83 KIAS and best rate is 71 KIAS. Landing approch, normal approach is 83 KIAS, too. maximum glide speed is 83 KIAS. I use climb best rate for **best_glide**.

best_angle_climb_speed = 83 ; 0 ; Best angle climb speed (Kts)
approach_speed = 83 ; 0 ; Approach speed (Kts)
best_glide = 71 ; 0 ; Best Glide (Kts)

I use the climb, normal speed for **climb_speed**.

climb_speed = 104 ; 65 ; Climb speed (Kts)

The POH takeoff, normal climb out speed is 87 KIAS. I wonder where the Asobo number is coming from.

takeoff_speed = 87 ; 55 ; Takeoff Speed (Kts)

The POH power off stalling speed depends on the weight and bank angle. For weight 1625 lbs it is 52.1 KIAS at 0°, 55.6 KIAS at 30°, 61.7 KIAS at 45° and 73.9 KIAS at 60°.

full_flaps_stall_speed = 52 ; Knots True (KTAS)
flaps_up_stall_speed = 52 ; Knots True (KTAS)

CAP10C technical data

The CAP 10C technical data is given in metric units. I do not know if Asobo just read the wrong POH or if Asobo had difficulties to convert from metric units to the strange units the FS2020 uses. But here are my parameters straight out of the POH.

1.3.1 Wings

wing_area = 116.8 ; Wing area S (SQUARE FEET) – 10.85 m^2
wing_span = 26.44 ; Wing span b (FEET) – 8.06 m
wing_dihedral = 5 ; Dihedral angle Lambda (DEGREES) – 5°
wing_twist = 0 ; Wing twist epsilon (DEGREES) – 0°

1.3.2 Ailerons

aileron_area = 7.2 ; (SQUARE FEET) – 0.67m^2
aileron_up_limit = 25 ; Aileron max deflection angle (DEGREES) - 25°
aileron_down_limit = 25 ; Aileron max deflection down angle (absolute value) (DEGREES) – 25°

1.3.3 Flaps

flaps-position.0 = 0, 90, 0 ; - 0°
flaps-position.1 = 15, 88, 0.25 ; - 15°
flaps-position.2 = 40, 86, 1 ; - 40°

1.3.4 Fuselage

fuselage_length = 23 ; Nose to tail (FEET) – 7m
fuselage_diameter = 3.46 ; - 1.054m

1.3.5 Horizontal stabilizer

htail_span = 9.5 ; Horizontal tail span (FEET) – 2.9m
htail_area = 20 ; Horizontal tail area (SQUARE FEET) – 1.86m^2
elevator_area = 9.3 ; Elevator area (SQUARE FEET) – 0.86m^2
elevator_up_limit = 25 ; Elevator max deflection up angle (DEGREES) - 25°
elevator_down_limit = 25 ; Elevator max deflection down angle (absolute value) (DEGREES) – 25°

1.3.6 Electrical elevator trim tab

elevator_trim_limit = 17 ; Elevator trim max angle (absolute value) (DEGREES) – 17°
elevator_trim_neutral = 0 ; Elevator trim default angle (absolute value) (DEGREES)

Note: The elevator_trim_neutral is not given in the POH.

1.3.7 Vertical stabilizer

vtail_span = 5.2 ; Vertical tail span (FEET) – 1.59m
vtail_area = 14.2 ; Vertical tail area (SQUARE FEET) – 1.316m^2
rudder_area = 7.1 ; (SQUARE FEET) – 0.659m^2
rudder_limit = 18 ; Rudder max deflection angle (absolute value) (DEGREES) - 18°
rudder_trim_limit = 0 ; Rudder trim max deflection angle (absolute value) (DEGREES)

Note: The rudder_trim_limit is not given in the POH.

1.3.8 Landing gear

The distance between the two front wheels is 2.06m. This translates to two times 3.4 ft.

point.1 = 1, -1.3, -3.4, -3.05, 1500, 1, 0.62, 0, 0.131, 2.5, 0.33, 0, 0, 2, 0, 0 ; gear main
point.2 = 1, -1.3,   3.4, -3.05, 1500, 2, 0.62, 0, 0.131, 2.5, 0.33, 0, 0, 3, 0, 0 ; gear main

1.8 Certified maximum weights

max_gross_weight = 1720 ; (LBS) – Category A 780kg

1.9 Characteristic weights

empty_weight = 1190 ; (LBS) – 540kg

2.2.2 Category A

cruise_speed = 127 ; Knots True (KTAS) – Va maximum speed at which you can fully deflect the control surfaces
max_flaps_extended = 86 ; - Vfe maximum speed with flaps extended
max_indicated_speed = 184 ; Red line (KIAS) – Vne never exceed
normal_operating_speed = 162 ; Vno maximum normal operation

2.10 LIMIT LOAD FACTORS

positive_g_limit_flaps_up = 6 ; Flap positive load limit when up.
negative_g_limit_flaps_up = -4.5 ; Flap negative load limit when up.
positive_g_limit_flaps_down = 2 ; Flap positive load limit when down.
negative_g_limit_flaps_down = -2 ; Flap negative load limit when down.
load_safety_factor = 1.1 ; 1.5 ; Flap negative load limit when down.

4.2 Speeds

takeoff_speed = 59 ; Takeoff Speed (Kts) - Takeoff
climb_speed = 86 ; Climb speed (Kts) - Normal climb
best_angle_climb_speed = 65 ; Best angle climb speed (Kts) - Best climb angle (Vx), Cat. A
approach_speed = 65 ; Approach speed (Kts) – Approach, full flaps

4.3.9 Takeoff

rotation_speed_min = 27 ; Min speed required (Kts) – Tail up ?

5.4 Stall speed

flaps_up_stall_speed = 54 ; Knots True (KTAS) – weight 1830 lb, flaps clean
full_flaps_stall_speed = 46 ; Knots True (KTAS) - weight 1830 lb, flaps 40°

5.9 Glide characteristics

best_glide = 76 ; Best Glide (Kts) – Vi

6.4.3 Loading category A

Balance must be between 20% and 26% (category A).

Pitts S-2S weight and balance

The POH gives a definition of POH FS: "FS 00.0 is located 91.81 inches [7.65 ft] forward of lower wing leading edge". This point is in front of the airplane nose. The POH gives other locations that are relative to the POH FS:

fuel main = 81.32 in = +10.49 in [0.9 ft] to lower wing leading edge
pilot fwd = 105.15 in = -13.34 in [1.1 ft] to lower wing leading edge
pilot rear = 136.5 in = -44.69 in [3.7 ft] to lower wing leading edge

The FS2020 coordinate system has the origin "somewhere" in the airplane. I use the distance between nose and origin to mark the origin in the airplane view. The nose is 6.5 ft away from origin as **point.3** tells us.

point.3 = 17, 6.5, 0,   0, … ; nose

We use the S-2S length of 17.4 ft to determine the scale of the airplane drawing and place the simulator origin 6.5 ft from the nose as green dot in the drawing:
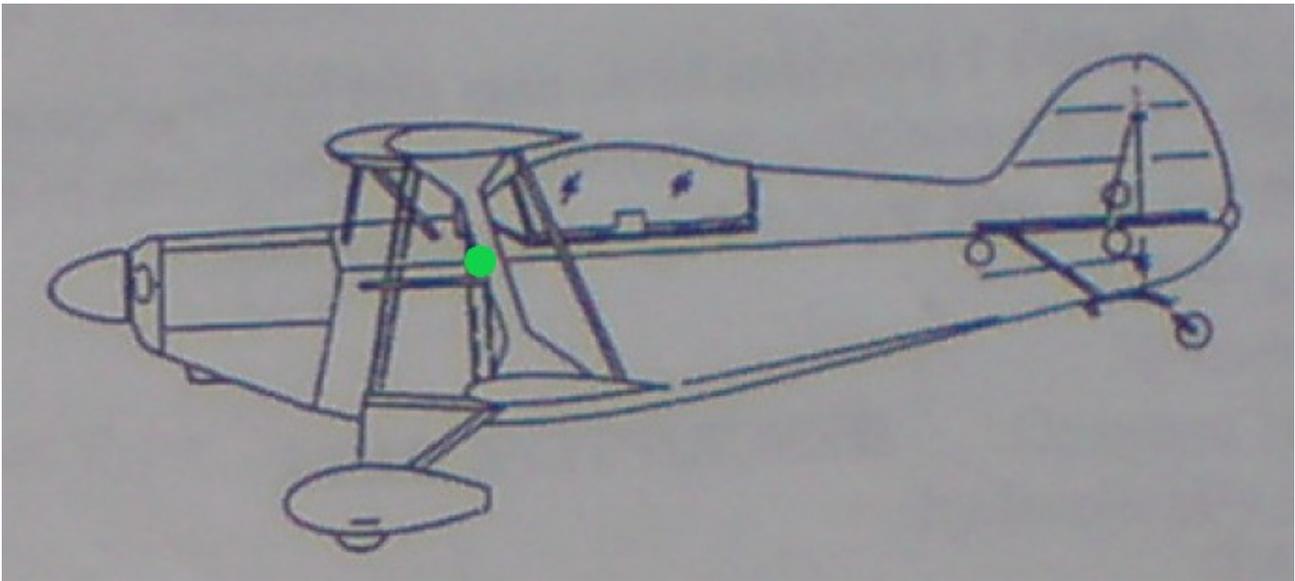
We see that the flight model origin is the lower wing leading edge, too.

Next we set the fuel main and pilot rear locations in the flight model. **station_load.0** is pilot location, **Center1** is fuel tank location. Because I do not know from POH, I set lateral and vertical position to 0.

station_load.0 = 170, -3.7, 0, 0, TT:MENU.PAYLOAD.PILOT, 1 ; 150, -4, 0, 1, TT:MENU.PAYLOAD.PILOT, 1

Center1 = 0.9, 0, 0, 24, 1 ; -1, 0, -0.86, 20, 1

Now I balance the airplane to 25% MAC. After some experimentation I get:

empty_weight_CG_position = 0.24, 0, 0 ; 0.45, 0, -0.75 ; Position of airplane empty weight CG relative to reference datum (FEET), z, x, y

Again I set lateral and vertical position to 0 because I don't know better.

CAP 10C weight and balance

The aerobatics flight is called Category A in the POH. The rules are:

2.9 FLIGHT

Cat. A: - aerobatics authorised
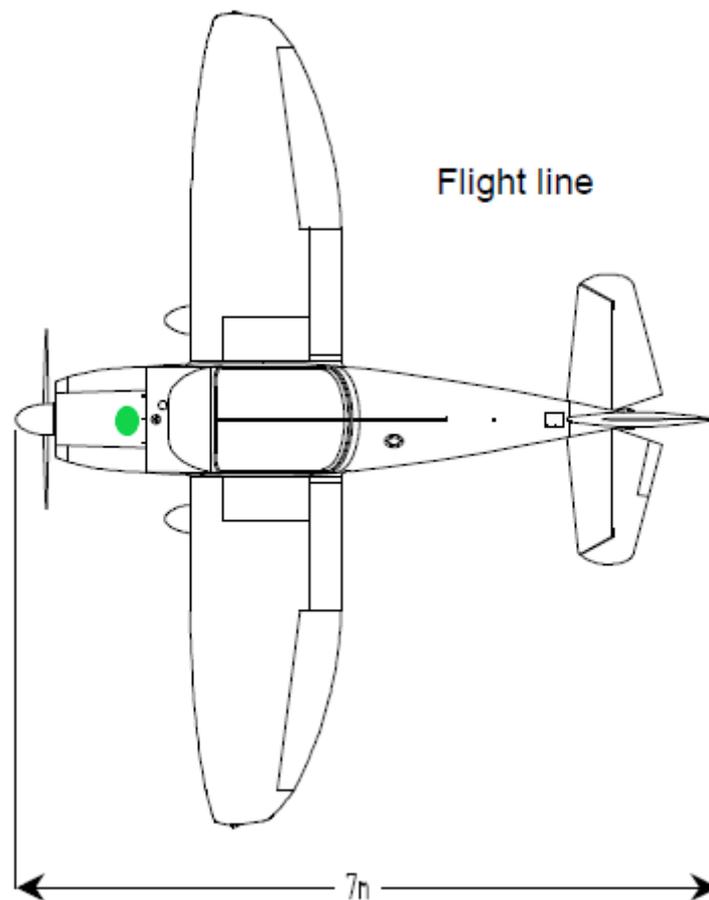
      - powered spins forbidden

For aerobatic flight, only the fwd tank must be used. The aft tank must be empty.

Flaps must be retracted for aerobatic flight.

The nose is 3.8 ft [1.16m] away from the coordinate system origin as **point.3** tells us.

Point.3 = 17, 3.8,   0,   1.5, ... ; nose

The origin is the green dot in the airplane top view.

Flight line

7n

Roll rate measurement

I make a simple roll rate measurement. Give full throttle. Got to 4000 ft altitude. Choose an angle of attack that gives 120 KIAS. Now give full aileron – nothing else. This is not how an aerobatics pilot flies a roll, but it is simple, every technician can do it. Let the airplane roll until the speed is Vne (never exceed speed).

If you video this test, you can use "Windows Media Player" to review. I checked that the Extra needs only 1 second per roll and the Pitts needs only 3 seconds for 2 rolls.

Without video you recognize how long the "brake time" is, the time between you bring stick in neutral position and the airplane stops rolling. Real pilots comments are different. Some say the Pitts and Extra stop rolling immediate, other say that you need a lot of training to fly delayed rolls where you stop at 90°, 180°, 270°. This long training time implies that real airplane have "brake time", too.

Climb rate measurement

In the Extra 330LX POH (Information manual)[7] I found the following climb rate diagram:

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7   https://www.extraaircraft.com/techservice.php
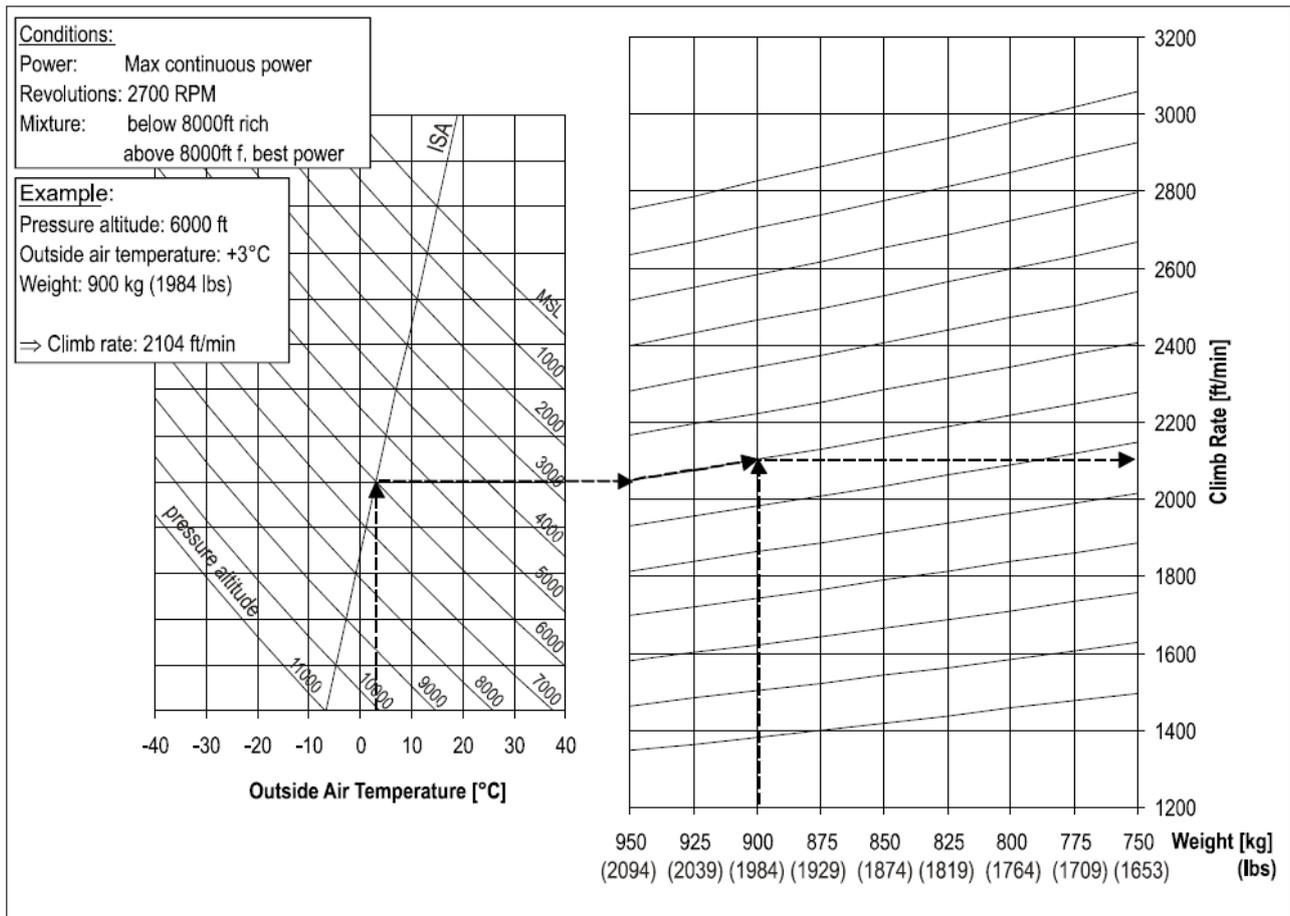
ISA is the standard atmospheric condition 1013.25hPa, 15°C at mean sea level (MSL). The climb rate is defined in dependence of temperature, altitude and weight. This is a nice example of a flight envelope! The best value of 3050ft/min you get at 15°C, MSL and minimum weight. Best rate-of-climb speed Vy is 88 KIAS.

Is it possible to make FS2020 simulate this flight envelope? I do not know.

Sawtooth measurement method

I do not know if there is an "official" method to measure climb rate. In the german documentation "Bestimmen von Flugleistungen und -eigenschaften aus Flugversuchsdaten der Muster Cessna 172 und Piper Archer"[8] I found the "sawtooth method".

The airplane flies on a given altitude with a given airspeed. For the measurement the altitude varies by 400ft to 600ft. The climb rate is altitude difference divided by time difference.

The V.SPEED display in the flight simulator non-cockpit view has the unit feet per minute – at least this is my conclusion.

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8   university of applied sciences FACHBEREICH FAHRZEUGTECHNIK UND FLUGZEUGBAU hamburg; Oliver Meins (Prof. Dr.-Ing. Dieter Scholz, Scholz at fzt.fh-hamburg.de); 24.Sep.2001