Airplane	**Cirrus SR20**
ADS	**V433**

Introduction

The goal of the validation process is to determine the accuracy of the ADS's algorithms to model an airplane of a given configuration. Validation consists in comparing the results of a series of measurements made during flight tests (FT) on a particular aircraft with the results of modelling carried out with the ADS software on the same aircraft (ADS). If no flight test results are available, the data are taken from the flight manual (FM) and from the Type Certificate Data Sheet (TCDS)

The algorithms used to compute the aerodynamic, weight and balance, stability and performance are described at the end of this report.

Figure 1 – Cirrus SR20 – long span (11.67 m)

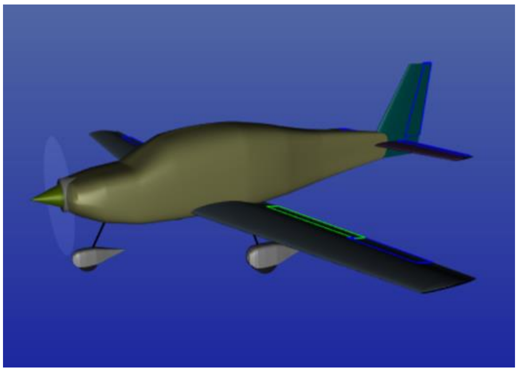

Figure 2 – Cirrus SR20 3D model

Methodology

The analysis takes place in 3 steps:

- Step 1: make the reverse engineering of the aircraft
- Step 2: calculate the performance of the aircraft for different flight conditions
- Step 3: present and comment the results

List of assumptions

- Wing incidence: 3°
- Wing Center of Gravity (CG) 40%
- Wing airfoil profile: Roncz-Marske 7
- Horizontal tail airfoil profile: NACA-0009
- Vertical tail airfoil profile: NACA-0009
- Airplane CG position 27%

List of references

- Pilot's Operating Handbook and FAA Approved Airplane Flight Manual Cirrus SR20 (2020)
- EASA Type Certificate for Cirrus SR20, SR22 and SR22T

Reverse Engineering

The reverse analysis consists to generate the 3D-Model of the aircraft and to specify its characteristics and performance. The aircraft will then be analyzed in detail in order to determine its mass efficiency and its aerodynamic efficiency for different flight conditions. A large number of statistics data will be generated.

Results

Drag efficiency

From the reverse engineering, the equivalent friction drag coefficient (Cfe) and the interference drag coefficient (Cd_{int}) have been computed for different altitudes (Alt) and power settings (PS), as shown in Table 1.

Table 1 – Flight parameters for cruise condition

PS [%]	Alt [m]	V_{cr}[km/h]	**Cfe**	**Cd_{int}**
90	610	289	**0.00545**	**19.1**
84	1219	287	**0.00547**	**18.6**
78	1829	285	**0.00544**	**17.6**
72	2438	282	**0.00544**	**16.9**
67	3048	278	**0.00561**	**18.7**
62	3658	272	**0.00578**	**20.4**
57	4267	267	**0.00581**	**20.2**

Lift efficiency

The lift efficiency is the ratio between the maximum lift coefficient (Cl_{Mx}) computed from the stall speed performance flaps up and the maximum lift coefficient computed from the theory taking into account the wing geometry. The high lift device efficiency is the ratio between the maximum lift increment (ΔCl_{Mx}) computed from the stall speed performance flaps down and the maximum lift increment computed from the theory taking into account the flap type and geometry. Lower than 1 means that the theory overestimates the value.

Table 2 – Lift efficiency

	FM	ADS	**η [%]**
Cl_{Mx}	1.34	1.43	**97.2**
ΔCl_{Mx}	0.44	0.42	**105.1**

Mass efficiency

The mass efficiency (MCF) is the ratio between the empty weight given by the manufacturer and the empty weight computed from the theory taking into account the geometry of every components of the aircraft. The theory makes the assumption that the aircraft is build with light alloy. The MCF takes into account the material but also the ability of the manufacturer to build a light structure, or not. MCF higher than 1 means that the aircraft is heavier than it should be if built with light alloy and optimized in weight.

Table 3 – Mass efficiency

MCF	**1.27**

Performance Analysis

The performance analysis consists to compute the performance of the aircraft for a specific flight condition. A flight condition is defined by the flight weight, the flight altitude, the power setting and the CG position. The total zero lift drag is computed from the interference drag coefficient which is supposed to be the same (16.9) for every flight conditions (Cruise, Takeoff (TO), Landing (Ld), Maximum Rate of Climb (RC_{Mx})).

Stall

The stall speeds (V_s) are calculated by ADS and compared with the stall speeds given in the flight manual for a specific flight condition. The stall speeds with flaps up and down computed by ADS and given by the flight manual are presented in Table 4.

A first fudge factor (FF_{ClMx}) is used for the flaps up flight condition to taking into account that the maximum lift coefficient of the lift curve generated by XFoil is most of the time overestimated. The second fudge factor ($FF\Delta_{ClMx}$) is used for the flaps down condition to adjust the maximum lift increment due to the flap deflection. The magnitude of both fudge factors is determined from reverse engineering and is considered to be 0.972 for the first one and 1.05 for the second in the current airplane.

Table 4 – V_s @ 1429kg, CG @ 27% MAC, Alt @ SL, FF_{ClMx}=0.972 and $FF\Delta_{ClMx}$ =1.05

	FM	ADS	**Δ [%]**
$V_{s\ \text{flaps up}}$ [km/h]	128	127	**-0.8**
$V_{s\ \text{flaps down 100\%}}$ [km/h]	111	113	**1.8**

Takeoff

The takeoff is calculated according to the runway slope and surface, headwind speed (HW), flap deflection (Flap dflct), CG position, flight weight and rotation time (Rot. T). The takeoff distance computed by ADS and given by the flight manual are presented in Table 5 for an asphalt runway.

Table 5 – Takeoff Distance considering Rot. T=2s and Flap dflct =16°

					FM	ADS	**Δ**
Rwy alt [m]	Mass [kg]	HW [km/h]	V_{LO} [km/h]	Rot. T [s]	TO Run [m]	TO Run [m]	**TO Run [%]**
0	1429	0	139	2	514	527	**0.6**
0	1429	22	139	2	462	456	**-1.3**
0	1179	0	128	2	312	360	**15.4**
0	1179	22	128	2	281	316	**12.5**
914	1429	0	145	2	654	633	**-3.2**
914	1429	22	145	2	589	561	**-4.8**
914	1179	0	134	2	397	437	**10.1**
914	1179	22	134	2	358	385	**7.5**

The deviation is higher for a lighter flight weight and overall it decreases when headwind is added. The rotation time should be within a range of values (1s to 3s) according to the literature and should be adjusted for a given aircraft in order to obtain a good accuracy in the takeoff distance. The value chosen will be the same for every takeoff since it is assumed that the force applied on the elevator by the pilot is the same. An explanation for the large deviation when the flight weight is reduced can be that a given aircraft with a lighter weight might rotate faster than if it has a heavier weight since it reacts faster to pilot's inputs.

Maximum Rate of Climb

The RC_{Mx} and its associated flight speed (V_y), are presented in Table 6 for a flight weight of 1429kg and in Table 7**Erreur ! Source du renvoi introuvable.** for a flight weight of 1179kg.

Table 6 – RC_{Mx} @ 1429kg, CG @ 27% MAC, Alt @SL

	FM	ADS	**Δ [%]**
V_y [km/h]	180	180	**0**
RC [m/s]	4.39	4.40	**0.3**

Table 7 – RC_{Mx} @ 1179kg, CG @ 27% MAC, Alt @SL

	FM	ADS	**Δ [%]**
V_y [km/h]	180	158	**-12.2**
RC [m/s]	5.89	5.99	**1.5**

The RC @ 180km/h (V_y) is presented in Table 8 for a flight weight of 1179kg.

Table 8 – RC @ 1179kg, CG @ 27% MAC, Alt @SL, V_y = 180km/h

	FM	ADS	**Δ [%]**
RC [m/s]	5.89	5.887	**-0.05**

Cruise Speed

The computed cruise speed (ADS) for different altitudes and power settings is presented in Table 9.

Table 9 – V_{cr} @ 1179kg, CG @ 27% MAC

		FM	ADS	**Δ**
Alt [m]	PS [%]	V_{cr} [km/h]	V_{cr} [km/h]	**[%]**
610	90	289	292	**1.0**
1219	84	287	289	**0.7**
1829	78	285	286	**0.4**
2438	72	282	283	**0.4**
3048	67	278	280	**0.7**
3658	62	272	277	**1.8**
4267	57	267	272	**1.9**

Both computed values (ADS) and values taken from the flight manual (FM) are presented in Figure 3. The maximum deviation is less than 2%.

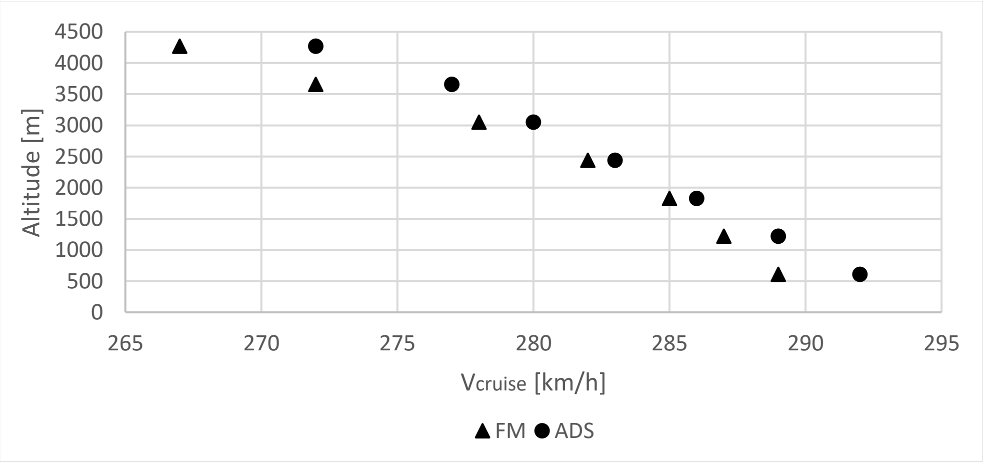

Figure 3 – Cruise speed (taken from FM and computed with ADS)

Landing

The landing distance depends on the runway surface, touchdown speed (V_{TD}) and flare time (Flr. T). The RFC (Rolling Friction Coefficient, brakes on) controls the brake action during the landing. This parameter can have a range of values [0.15 - 0.50] according to the runway surface and the pilot action on the brakes. The flare time is the time required for the aircraft to be rolling on the runway with all wheels on the surface. It starts when the main wheels hit the ground and ends as soon as the nosewheel touches the runway. The landing distance is calculated according to the runway slope and surface, headwind speed, flap deflection, CG position, flight weight and for a RFC equal to 0.39 which represents the friction coefficient on a paved runway and moderate action on the brakes. The conditions used to obtain the landing distance for an asphalt runway are presented in Table 10.

Table 10 – Landing distance for a flight weight of 1429kg and RFC=0.39

						FM	ADS	Δ
Rwy Alt [m]	Flap dflct [º]	HW [km/h]	V_{TD} [km/h]	Flr T [s]	RFC	Ld run [m]	Ld run [m]	Ld Run [%]
0	32	0	144	1	0.39	260	270	3.85
0	32	24	144	1	0.39	234	234	0.00
0	16	0	156	1	0.39	331	323	-2.42
0	16	24	156	1	0.39	298	283	-5.03
0	0	0	165	1	0.39	381	368	-3.41
0	0	24	165	1	0.39	343	325	-5.25
914	32	0	151	1	0.39	284	296	4.23
914	32	24	151	1	0.39	256	258	0.78
914	16	0	163	1	0.39	361	351	-2.77
914	16	24	163	1	0.39	325	310	-4.62
914	0	0	172	1	0.39	416	398	-4.33
914	0	24	172	1	0.39	375	353	-5.87

The deviation is influenced by the headwind and flap setting, as shown in Figure 4. The deviation depends slightly on the altitude and increases as the headwind increases for flap settings 50% and 0%. In contrast, for flaps at 100% increasing the headwind speed will result in a lower deviation.

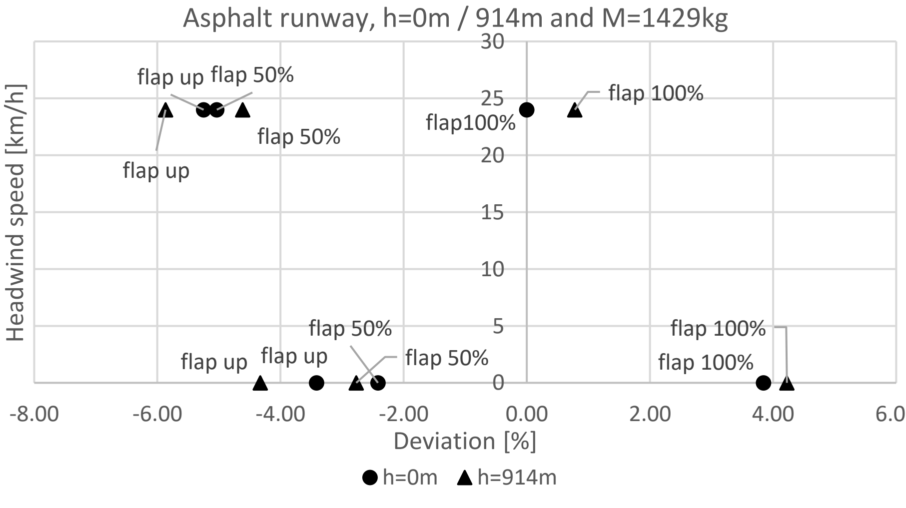

Figure 4 – Deviation in function of headwind and flap setting

Comments

The maximum lift is computed from the lift distribution over the lifting surface using the lifting line theory. The lift increment due to flap deflection is computed from the flap type and geometry

The total drag is computed making the sum of the drag of each component of the Aircraft, including the interference drag.

The empty weight is computed making the sum of the weight of each component of the aircraft. The weight of each component is computed from its geometry. A fudge factor may be used to take into account the material and the skills of the manufacturer.

The Center of Gravity position of the aircraft is computed from the mass and position of each component. The center of gravity is computed for different loading configuration. The CG range is computed to ensure stability and maneuverability.

The engine performance are computed from an engine database taking into account the flight conditions

The takeoff run is the distance between the brake release point and the point where the speed is equal to the liftoff speed and the plane lifts off. The mean acceleration is computed at several speeds, between these two limits, taking into account the engine thrust, the total drag, the wheel friction and the slope of the runway. The length of each segment is computed from the mean acceleration and the speed. The total distance is the sum of the distances travelled in each segment.

The rate of climb is computed at a given speed taking into account the engine thrust and the total drag of the airplane. The engine thrust is computed from the engine nominal power and takes into account the effects of altitude, the propeller efficiency and the installation efficiency. The total drag is the sum of the zero lift drag, induced drag and trim drag. The zero lift drag is computed by summing the drag of each component of the aircraft, including the interference drag.

The cruising speed is computed for a given flight condition taking into account the power setting, the flight weight, the center of gravity position and the flight altitude.

The stall speed is computed flaps up and flaps down taking into account the lift distribution on the wing. The stall is reached when one local lift coefficient reaches its maximum value. The lift distribution is computed from the lifting line theory and takes into account the airfoil profiles and the planform of the lifting surface. The aerodynamic data of each airfoil profile have been computed with XFoil.

Not included in this report but processed by ADS:

- Static stability
- Dynamic stability (free response (eigenmode), step response, harmonic response)
- Cost analysis (R&D, Operating, Breakeven, Market price)
- Optimization (performance, cost, shape)
- Sizing and location of each component/system
- Checking for interference between components

Sources

The ADSV4 computation engine is a compilation of the best algorithms, chosen for their excellent accuracy / time-to-compute ratio. The algorithms are extracted from academic & scientific publications and reference books such as USAF DATCOM, Roskam, Raymer, Torenbeek… Technical notes written by OAD complete them and are directly accessible via the software's interface

List of Symbols

ADS	Result computed by ADS	
Cd_{int}	Airplane equivalent interference drag coefficient	
Cfe	Airplane friction coefficient	
CG	Center of Gravity	% MAC
Cl_{Mx}	Maximum lift coefficient	
FF_{ClMx}	Fudge factor maximum lift coefficient	
$FF\Delta_{ClMx}$	Fudge factor maximum lift increment	
Flap dflct	Flap deflection	°
Flr. T	Landing flare time	s
FM	Value taken from the Flight Manual	
HW	Headwind speed	km/h
Ld_{Run}	Landing run	m
PS	Engine Power Setting	%
RC_{Mx}	Maximum Rate of Climb	m/s
RCF	Rolling friction coefficient	
Rot. T	Rotation time during takeoff	s
Rwy Alt	Runway altitude	m
TO_{Run}	Takeoff run	m
V_{cr}	Cruise Speed	km/h
V_{LO}	Liftoff Speed	km/h
V_S	Stall Speed	km/h
V_{TD}	Touchdown Speed	km/h
V_Y	Speed for best rate of climb	km/h
Δ	(ADS-FM)/FM	%
ΔCl_{Mx}	Maximum lift increment	