| Airplane | Diamond DA42 |
|---|---|
| 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 – Diamond DA42

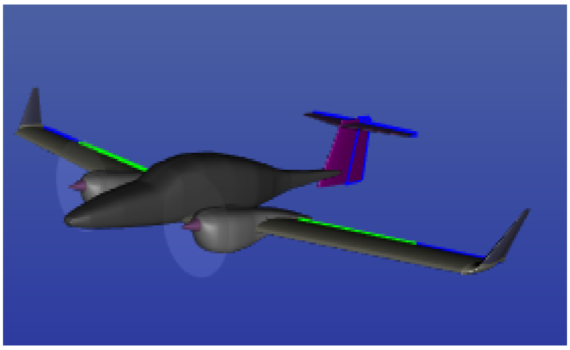

Figure 2 – Diamond DA42 3D model

## 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 2.5°
- Wing Center of Gravity (CG) 40%
- Horizontal tail airfoil profile: NACA 0009
- Vertical tail airfoil profile: NACA 0009
- Airplane (CG) position 21%
- Cruise Flight Mass 1700kg
- Touchdown speed ($V_{TD}$) for Mass 1700kg equal to approach speed
- $V_{TD}$ for Mass 1400kg equal to 90% of the approach speed

## List of references

- Pilot's Handbook Diamond DA42 (2005)
- EASA Type Certificate for Diamond DA42

# 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** | **$Cd_{int}$** |
|---|---|---|---|---|
| 100 | 1219 | 294 | **0.00630** | **13.6** |
| 90 | 3048 | 302 | **0.00608** | **9** |
| 80 | 4267 | 300 | **0.00602** | **7.1** |
| 70 | 4877 | 289 | **0.00602** | **6.7** |
| 60 | 5486 | 276 | **0.00575** | **1.7** |
| 50 | 5486 | 272 | **0.00533** | **-6.4** |

### 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 ($\Delta Cl_{Mx}$) 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 [%]** |
|---|---|---|---|
| $Cl_{Mx}$ | 1.48 | 1.56 | **90.2** |
| $\Delta Cl_{Mx}$ | 0.40 | 0.46 | **87.3** |

### 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 | **1.14** |

# 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 (8.5) 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 A first fudge factor (FFClMx) 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 (FFΔClMx) 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 0.902 for the first one and 0.873 for the second in the current airplane.

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 0.902 for the first one and 0.873 for the second in the current airplane.

Table 4 – $V_s$ @ 1700kg, CG @ 21% MAC, Alt @ SL, $FF_{ClMx}$=0.902 and $FF\Delta_{ClMx}$ =0.873

| | FM | ADS | **Δ [%]** |
|---|---|---|---|
| $V_{s\ flaps\ up}$ [km/h] | 115 | 118 | **2.5** |
| $V_{s\ flaps\ down\ 100\%}$ [km/h] | 102 | 105 | **2.9** |

## 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 the same Rot. T

| | | | | | | FM | ADS | Δ |
|---|---|---|---|---|---|---|---|---|
| Rwy alt [m] | Mass [kg] | Flap dflct [º] | HW [km/h] | $V_{LO}$ [km/h] | Rot. T [s] | TO Run [m] | TO Run [m] | TO Run [%] |
| 0 | 1700 | 0 | 0 | 130 | 1 | 350 | 340 | -2.86 |
| 0 | 1700 | 0 | 22 | 130 | 1 | 300 | 296 | -1.33 |
| 0 | 1400 | 0 | 0 | 130 | 1 | 280 | 279 | -0.36 |
| 0 | 1400 | 0 | 22 | 130 | 1 | 240 | 243 | 1.25 |
| 1219 | 1700 | 0 | 0 | 138 | 1 | 395 | 400 | 1.27 |
| 1219 | 1700 | 0 | 22 | 138 | 1 | 340 | 351 | 3.24 |
| 1219 | 1400 | 0 | 0 | 138 | 1 | 320 | 327 | 2.19 |
| 1219 | 1400 | 0 | 22 | 138 | 1 | 280 | 287 | 2.50 |

Overall, the deviation remains below 3% and slightly increases with headwind speed. 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.

## Maximum Rate of Climb

The $RC_{Mx}$ and its associated flight speed ($V_y$), are presented in Table 6 for a flight weight of 1700kg and in Table 7**Erreur ! Source du renvoi introuvable.** for a flight weight of 1500kg.

Table 6 – $RC_{Mx}$ @ 1700kg, CG @ 21% MAC, Alt @SL

| | FM | ADS | **Δ [%]** |
|---|---|---|---|
| $V_y$ [km/h] | 157 | 155 | **-1.3** |
| RC [m/s] | 5.74 | 5.55 | **-3.3** |

Table 7 – $RC_{Mx}$ @ 1500kg, CG @ 21% MAC, Alt @SL

| | FM | ADS | **Δ [%]** |
|---|---|---|---|
| $V_y$ [km/h] | 157 | 155 | **-1.3** |
| RC [m/s] | 6.86 | 6.64 | **-3.2** |

The $RC_{Mx}$ and its associated flight speed ($V_y$) when one engine is inoperative are shown in Table 8. The rate of climb is computed taking into account the additional drag due to the stopped propeller and the drag due to slipping.

Table 8 – One engine inoperative, $RC_{Mx}$ @ 1700kg, CG @ 21% MAC, Alt @SL

| | FM | ADS | **Δ [%]** |
|---|---|---|---|
| $V_y$ [km/h] | 152 | 144 | **-5.3** |
| RC [m/s] | 1.12 | 1.09 | **-2.7** |

## Cruise Speed

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

Table 9 – $V_{cr}$ @ 1700kg, CG @ 21% MAC

| | | FM | ADS | **Δ** |
|---|---|---|---|---|
| Alt [m] | PS [%] | $V_{cr}$ [km/h] | $V_{cr}$ [km/h] | **[%]** |
| 1219 | 100 | 294 | 301 | **2.4** |
| 3048 | 90 | 302 | 304 | **0.7** |
| 4267 | 80 | 300 | 301 | **0.3** |
| 4877 | 70 | 289 | 290 | **0.4** |
| 5486 | 60 | 276 | 274 | **-0.7** |
| 5486 | 50 | 272 | 245 | **-2.8** |

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

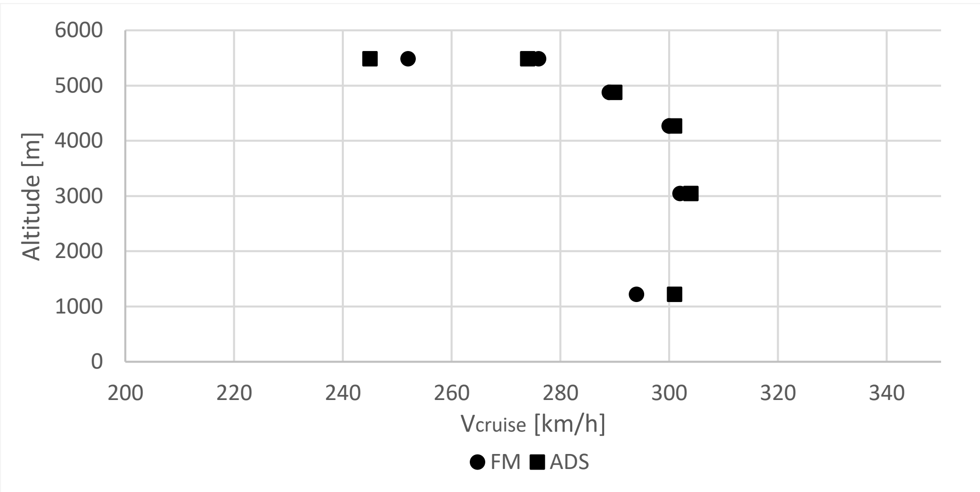


Figure 3 – Cruise speed (taken from FM and computed with ADS)

## 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 0.29 which represents the friction coefficient on a concrete runway and high action of the pilot on the brakes. The conditions used to obtain the landing distance are presented in Table 10.

Table 10 – Landing distance considering a constant RFC=0.29.

| | | | | | | | FM | ADS | Δ |
|---|---|---|---|---|---|---|---|---|---|
| Rwy Alt [m] | Mass[kg] | Flap dflct [º] | HW [km/h] | $V_{TD}$ [km/h] | Flr T[s] | RFC | Ld run [m] | Ld run [m] | Ld Run [%] |
| 0 | 1650 | 42 | 0 | 141 | 1 | 0.29 | 310 | 310 | 0.00 |
| 0 | 1650 | 42 | 24 | 141 | 1 | 0.29 | 270 | 270 | 0.00 |
| 1219 | 1650 | 42 | 0 | 150 | 1 | 0.29 | 350 | 348 | -0.57 |
| 1219 | 1650 | 42 | 24 | 150 | 1 | 0.29 | 300 | 307 | 2.33 |
| 0 | 1400 | 42 | 0 | 127 | 1 | 0.29 | 260 | 255 | -1.92 |
| 0 | 1400 | 42 | 24 | 127 | 1 | 0.29 | 220 | 218 | -0.91 |
| 1219 | 1400 | 42 | 0 | 135 | 1 | 0.29 | 295 | 286 | -3.05 |
| 1219 | 1400 | 42 | 24 | 135 | 1 | 0.29 | 250 | 247 | -1.20 |

The deviation is influenced by the headwind and the altitude, as shown in Figure 4 for a flight weight of 1650kg and in Figure 5 for a flight weight of 1400kg. For a constant flap setting and flight weight the deviation increases slightly with the altitude. The maximum deviation is approximately 3%.

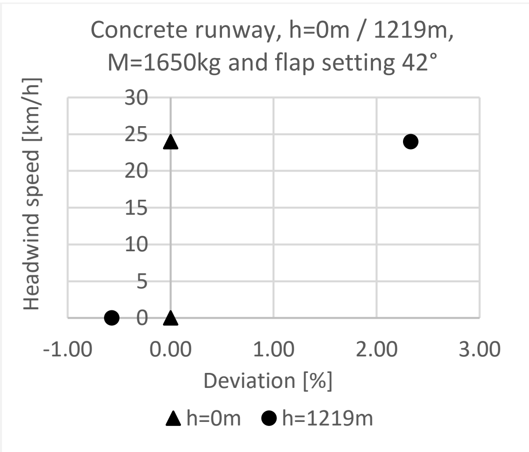


Figure 4 – Deviation in function of headwind and altitude

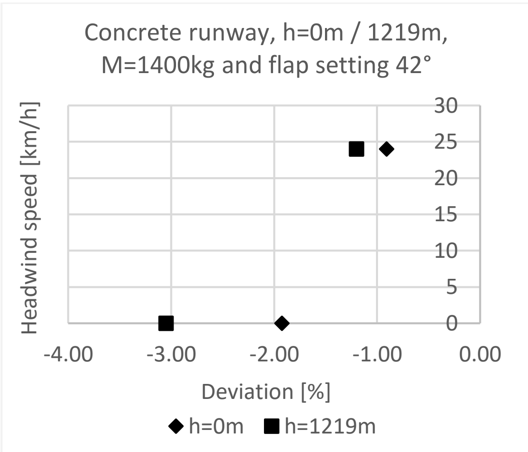


Figure 5 – Altitude and headwind versus deviation

## 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 |
| MCF | Mass efficiency | |
| 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 | % |
| $\Delta Cl_{Mx}$ | Maximum lift increment | |