Technical Note

Validation of PCA2000 V2.1

Ref. NT04001EN

April 2004

Key words : PCA2000, validation, flight tests, modelling.

Abstract:

The objective of this study is to validate the “modelling” module of PCA2000 V2.1. Validation involves comparing the results of a series of measurements taken during flight tests on a particular aircraft with the results of modelling performed with the PCA2000 V2.1 software on the same aircraft.

Glasair III

The flight measurements were taken on a Glasair III by the American association CAFE 400.

The table hereafter presents the validation results. It indicates the existing deviations between the measurement and the modelling for the different analysed flight phases. The small deviations observed tend to indicate that the current version of the model may be considered as a correct approach to reality.

Phase of flight :	Measurements		Variation
Take off run	427 m	410 m	-4%
Best rate of climb speed (Vy)	209 km/h	211 km/h	+0,1%
Rate of climb at 256 km/h	10,56 m/s	10,84 m/s	+2,7%
Cruising speed	406 km/h	404 km/h	-0,5%

Symbols et notations:

V (flight speed), TM (rate of climb), Pd (available engine power), D (drag), D0 (zero lift drag), DL (induced drag), cd (drag coefficient), cd0 (zero lift drag coefficient), Rh (propeller efficiency).

Methodology:

It involves finding by calculation the results of measurements taken during flight tests on a given aircraft. The measured performances that will be analysed are:

- The take-off distance,
- The flight speed which corresponds to the best rate of climb (Vy),
- The climbing rate to the flight speed of 256 km/h,
- The cruising speed.

The study takes place in 4 phases:

1. The first phase involves making a synthesis of the results of the measurements taken during the tests for the 3 flight phases: take-off, climbing and cruising.
2. The second phase involves analysing the tested aircraft so as to know its geometric characteristics together with its mass and aerodynamic qualities. This information will subsequently be utilised by the modelling software to calculate the performances of the tested aircraft for all the flight phases under consideration.
3. The third phase involves using the modelling program to calculate the performances of the tested aircraft for the flight phases corresponding to take-off, climbing and cruising.
4. The fourth and last phase involves analysing the results provided by modelling and measuring the existing deviation between the result of the measurements taken in flight and the result of modelling.

1. Flight test results

Flight tests were performed by the American association CAFE400. Full test reports can be downloaded from the Association's web site (www.cafefoundation.org). The table hereafter contains the performances measured for the flight phases corresponding to cruising, climbing, take-off and stall.

Cruise (75%, 8000ft)	
Flight speed	406 km/h
Flight weight	1062 kg
Flight altitude	2438 m
Maximum rate of climb speed (Vy)	
Flight speed	209 km/h
Rate of climb at given speed	
Rate of climb	10.56 m/s
Flight speed	256 km/h
Flight weight	1029 kg
Flight altitude	914 m
Take off	
Take off run	427 m
Take off speed	157 km/h
Take off weight	1084 kg
Flight altitude	36 m
Runway surface	Concrete
Runway slope	0.0 %
Wind speed	0 km/h
Stall	
Stall speed	119 km/h
Flight weight	1023 kg
Flight altitude	2438 m

2. Airplane analysis

The Glasair III is an aircraft built by composite technology with a retracting gear. The tested version is powered by a Lycoming IO-540-K1B5 engine and is fitted with a hydraulic constant speed propeller. Additional information can be obtained from the manufacturer's web site (www.newglasair.com).

General :

Model	Glasair III
Manufacturer	Stoddard Hamilton Aircraft Corp
Classification	Light airplane
Type	Recreational
Seat number	2 seats side by side
General layout	Conventional
Wing	Cantilever, tapered, straight, low position
Tails	Conventional, fuselage mounted
Landing gear	Retractable, tricycle, wing mounted
Propulsion	Single, Piston, tractor, fuselage mounted
Structure	Composite, fibreglass
Airworthiness requirements	FAR Part 23

Fuel system :

Fuel capacity	216 l

Main dimensions :

Overall length	6.502 m

Wing :

Surface	9.033 m²
Span	8.230 m
Root chord	1.363 m
Tip chord	0.832 m
Aspect ratio	7.50
Tapered ratio	0.61
Sweep angle	2.0 °
Twist	0.0 °
Airfoil at root	LS(1)-0413
Airfoil at tip	LS(1)-0413
Fuel tank capacity	216 l

High lift device :

Type	Simple flaps
Relative span	42.0 %
Relative chord	20.0 %
Maximum deflection	45.0 °

Horizontal tail :

Surface	1.510 m²
Span	2.642 m
Root chord	0.710 m
Tip chord	0.432 m
Aspect ratio	4.62
Tapered ratio	0.61
Sweep angle	8.0 °
Twist	0.0 °
Tail volume	0.49
Surface / Wing surface	0.17

Airfoil	Undefined 15%

Vertical tail :

Surface	1.059 m²
Span	1.308 m
Root chord	1.185 m
Tip chord	0.435 m
Aspect ratio	1.62
Tapered ratio	0.37
Sweep angle	40.0 °
Twist	0 °
Tail volume	0.102
Surface / Wing surface	0.12
Airfoil	Undefined 15%

Fuselage :

Height max.	1.077 m
Width max.	1.095 m
Length	6.299 m
Length of constant section	0.000 m
Frontal form coefficient	0.914
Lateral form coefficient	1.927

Landing gear :

Main - Tires	5.00-5
Main - Fairing	no
Auxiliary - Tires	3.50-6
Auxiliary - Fairing	no

Engine :

Engine - Model	IO-540-K1B5
Manufacturer	Lycoming
Maximum continuous power	223.710 kW

Propeller :

Type	Constant speed
Blade number	2
Material	Aluminium
Diameter	2.134 m

Weight :

Empty weight	737.0 kg
Maximum take off weight	1134.0 kg
Useful weight	397.0 kg
Fuel weight	155.5 kg

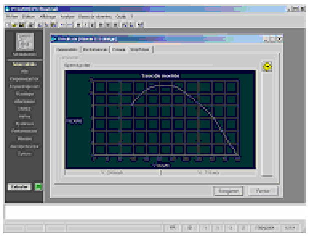
Aerodynamics :

Maximum lift coefficient	2.03
Maximum wing loading	125.5 kg/m²
Wing loading at empty weight	81.6 kg/m²
Friction coefficient (cruise)	0.0051
Induced drag coefficient (cruise)	0.88

3. Flight performances computed with PCA2000 V2.1

Cruising speed

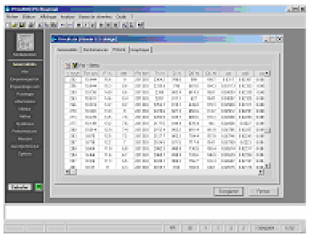
Flight speed	404 km/h
* Flight altitude	2438 m
Lift	10415 N
Drag - Zero lift	1076 N
Drag - Induced	79 N
Lift coefficient	0.19
Drag coefficient	0.021
Zero lift drag coefficient	0.020
Induced drag coefficient	0.001



* Specified value

Climb: Maximum rate of climb

Rate of climb	11.25 m/s
* Flight weight	1029 kg
* Flight altitude	914 m
Flight speed	211 km/h
Climb angle	11.1°
Climb slope	19.2%



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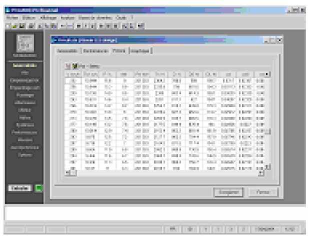
Climb: Rate of climb at given speed

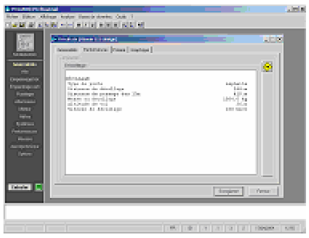
V (km/h)	TM (m/s)	Pd (kW)	Tn (N)	D (N)	D0 (N)	DL (N)	Cd (-)	cd0 (-)	Rh (-)
...									
242	11.12	201	2438	769	551	217	0.0336	0.0241	0.82
245	11.08	201	2414	775	564	211	0.0329	0.0239	0.82
249	11.03	201	2391	781	576	205	0.0323	0.0238	0.83
252	10.94	201	2364	788	589	199	0.0317	0.0236	0.83
256	10.84	201	2335	796	601	194	0.0311	0.0235	0.83
259	10.73	201	2308	803	614	189	0.0305	0.0233	0.83
263	10.63	201	2281	811	627	184	0.0300	0.0232	0.83
266	10.51	201	2254	819	639	179	0.0295	0.0231	0.84
270	10.40	201	2228	827	652	174	0.0291	0.0229	0.84
273	10.28	201	2202	835	665	170	0.0286	0.0228	0.84
...									



Note the evolution of the specific drag coefficient and the evolution of propeller efficiency according to flight speed.

Take off run

* Runway surface	Concrete
Take off run	264 m
Take of distance (15m)	410 m
* Take off weight	1084 kg
* Altitude	36 m
* Lift off speed	156 km/h



* Specified value

4. Analysis

The table below contains, for the different flight phases explored, the performances measured during flight tests, the performances calculated using the PCA2000 V2.1 modelling software and the deviation calculated between measurement and modelling.

Phase of flight :	**Measurements**		**Variation**
Take off run	427 m	410 m	-4%
Best rate of climb speed (Vy)	209 km/h	211 km/h	+0,1%
Rate of climb at 256 km/h	10,56 m/s	10,84 m/s	+2,7%
Cruising speed	406 km/h	404 km/h	-0,5%

PCA2000 V2.1 provides results relatively close to the values measured for all the flight phases under consideration.

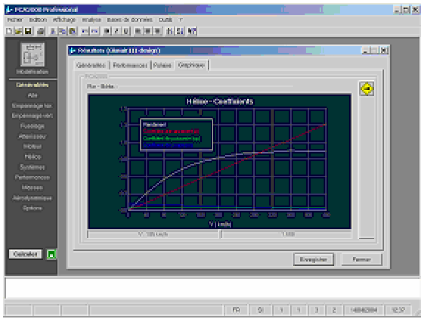
This accuracy of the results tends to indicate that the model calculates the evolution of the specific drag coefficient and of propeller efficiency realistically according to flight speed.

Determination of propeller efficiency

Propeller efficiency is calculated for each flight speed by utilising the charts of the NACA 640 report. This report summarises the results of wind-tunnel tests performed on twin-, three- and four-bladed propellers.

The curves of these different charts have been digitised so as to be able to utilise them automatically in the modelling software.

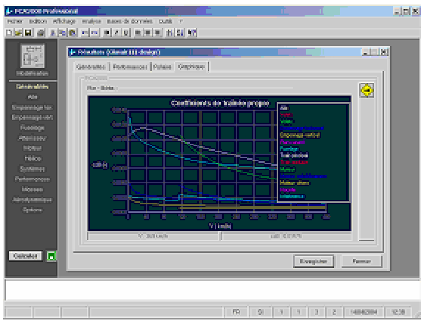
The image opposite is a screen copy of PCA2000 V2.1 and it shows the evolution of propeller efficiency according to flight speed.



Determining the specific drag of the aircraft

The specific drag of the aircraft is calculated for each flight speed by adding up the specific drags of the main components of the aircraft (wing, flaps, tail unit, fuselage, gear, engine …) and an interaction drag taking into account the mutual influence of all the parts of the airplane on the total drag of the aircraft. The algorithms used are taken from the work by Dr Jan Roskam entitled Airplane Design Part VI.

The image opposite is a screen copy of PCA2000 V2.1 and it shows the evolution of the specific drag coefficients according to flight speed.



To show the importance of a correct estimation of the zero lift drag coefficient, a first modelling was carried out by considering that the zero lift drag coefficient remains constant regardless of the flight speed. This simplifying hypothesis resulted, for a zero lift drag coefficient equivalent to the one observed at cruising speed, in an underestimation of **5.7%** of the best rate of climb speed (Vy) and an overestimation of **19.2%** of the rate of climb at 256 km/h.

Next, to show the importance of a correct estimation of propeller efficiency, a second modelling was carried out by considering that propeller efficiency was in the region of 66.5% during the climbing phase (Torenbeek, Synthesis of Subsonic Airplane Design, p165). This simplifying hypothesis resulted in an underestimation of **31%** of the best rate of climb speed (Vy) and an underestimation of **29%** of the rate of climb at 256 km/h.

A third modelling was carried out by combining the two previously considered simplifying hypotheses (constant zero lift drag coefficient and approximate propeller efficiency of 66.5%). This resulted in an underestimation of **27%** of the best rate of climb speed (Vy) and an underestimation of **22%** of the rate of