VARIABLE PITCH PROPELLER ALISPORT IDROVARIO 2-BLADE HS

LOAD AND STRESS ANALYSIS

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1 Overview

1.1 Introduction

Propeller

The Idrovario 2-blade HS propeller, manufactured by Alisport Srl / Cremella, Italy, is a hydraulically controlled variable-pitch propeller with carbon-fiber propeller blades.

The propeller hub is made of machine-milled aluminium and incorporates a propeller pitch adaption mechanism controlled by a hydraulic fluid. The control of the hydraulic fluid pressure is either achieved by a manual hydraulic pump for manual pitch control (by rotating a thumb-screw) or by an electro-hydraulic pump that is actuated by an electric governor for constant speed control.

The propeller blades are composed of epoxy pre-impregnated carbon-fiber fabrics and are therefore of very low mass and rotational inertia. The “HS” blade variant is especially designed for higher speed airplanes (IAS >= 100 kts) and is primarily used on the Rotax 912 engine family (912/912S/912iS).

Certification Regulations

The propeller Idrovario 2-blade HS will be used on experimental aircraft only (“Luftfahrzeuge der Sonderkategorie, Unterkategorie Eigenbau”). According to the corresponding SR 748.215.1 / paragraph 3.6, issued by the Federal Office of Civil Aviation (FOCA Switzerland), a propeller must fulfill requirements based on to CS-22 Subpart J.

Load / Stress Tests

Alisport Srl has conducted several load and stress tests on the Idrovario 2-blade HS propeller (listed in reverse chronological order):

	Doc. No.	Title	Description
1	FC-AV-Dn-026-1 18.07.2011	Test report: Tensile static test on blade model HS (s/n 504650)	Tensile static test of propeller blade on dynamometer up to material failure (blade rupture)
2	FC-AV-Dn-023-1 29.11.2010	Test report: Load test blade-hub attachment	Load test (tensile static test) of propeller hub attachment on dynamometer: Test up to material failure (failure of blade attachment) according to BCAR section S
3	FC-AV-A-004-2 04.08.2003	Fatigue test report of HS blade on 2-axis dynamometer (tensile + bending stress)	Fatigue test of HS blade on dynamometer: Static load of traction (simulates centrifugal force) and variable load in (1) orthogonal plane of blade and (2) plane of blade (simulates aerodynamic forces) Each test (1) and (2) lasted 24 hours and 36’450 (variable bending) load cycles.
3	FC_AV_M019 22.07.2003	Test report: Spin test JAR-P 170 for in-flight variable pitch propeller, blade type: HS	Spin test of Idrovario 2-blade HS on propeller test facility: JAR-P 170[a](1): Propeller run at MRS+10% at 75% pitch angle (10°) for 30 min. JAR-P 170[a](2): Propeller run at MRS+26% at 100% pitch angle (0°) for 30 min. *MRS = Maximum Rotational Speed*
5	FC_AV_M014 09.07.2003	Test report: Endurance test JAR-P 210 for in-flight variable pitch propellers	Dynamic endurance test of the propeller on a propeller test facility in 2 steps according to JAR-P 210[b](1)(A): (1) Takeoff power for 5 hours (2) 30 cycles of 10 min. each / 1 cycle = 5 min. at minimum power -> acceleration to 5 min. at takeoff power

In-Service Experience

The propeller Alisport Idrovario 2-blade HS is installed in numerous experimental, Ecolight and ultralight aircraft throughout Europe and has an excellent safety record (no known problems with the propeller to date), for example:

- Alpi Aviation Pioneer 200 and Pioneer 300 (total of approx. 800 aircraft)
- CZAW SportCruiser
- Flight Design CT Supra Light and CTLS
- DynAero MCR-01
- FlySynthesis Texan 580
- Rans S-6 Coyote II
- Corvus Phantom

The German representative for the Alpi Aviation Pioneer 200 and Pioneer 300, Mr. Michael Reiss, conservatively estimates the total flight hours of the Pioneer 300 to approximately 50'000 hours (probably even 80'000 – 100'000 hours), with most of the aircraft using the Alisport Idrovario 2-blade HS propeller. He states that the propeller didn't reveal any problems to date (email 15.01.2016):

> *Ich würde mal so etwa (sehr konservativ geschätzt) 5'0000 Stunden auf Pioneer 300 annehmen (wahrscheinlich sind es eher 80-100'000 Stunden). Mit dem Propeller gab es keine Probleme - auch nicht bei der Formationsflug-Staffel, wo die Props ja besonders belastet sind. Es sind die meisten P 300 mit Verstellprop unterwegs aber nicht alle.*

In the UK the propeller is frequently flown on aircraft like the CZAW SportCruiser and the Alpi Pioneer 300. The UK LAA Chief Engineer Francis Donaldson stated in an email (27.11.2015):

> *Unfortunately we have no test data for this propeller, which was accepted in the UK on the basis of in-service experience without problems in other countries. We have since had good results with this propeller in the UK also, with no known problems with it to date.*

Regarding long-term in-service experience, Idrovario Eng. Marco Agrati stated in an email (14.1.2016):

> *We confirm that we are producing these blades, having same design and production technology, since 11 years, without any known problem.*

1.2 Propeller Parameters

The propeller parameters are defined and provided by Alisport:

Propeller total mass (including hub):	$m_{Prop} = 5.8\ kg$
Mass of one HS-blade:	$m_{BladeTotal} = 0.85\ kg$
Propeller diameter:	$d = 1.76\ m$
Spinner diameter:	$d_{Spinner} = 0.18\ m$
Propeller maximum rotational speed (MRS):	$MRS = 2450\ rpm$ [1] [2]
Propeller moment of inertia:	$I_{Prop} = 3260\ kg \cdot cm^2$

[1] The (predefined) maximum rotational speed (MRS) is specified in multiple documents (Alisport load/endurance test reports, propeller user manual, Alisport webpage) and differs by some amount (min. 2'390 rpm (max. 2'650 rpm). For this present analysis, an MRS of 2'450 rpm is used (specification in original Alisport propeller user manual).

[2] The propeller is widely-used on Rotax 912/U or Rotax 912S/ULS engines. The maximum engine rotational speed of the Rotax 912 is 5'800 rpm which corresponds to a propeller rotational speed of 2'387 rpm (reduction gear 1:2.43).

1.3 Formulary

Length of one propeller blade: $l_{Blade} = \frac{d - d_{Spinner}}{2} = 0.79m$

It is known from technical literature that the center of gravity of a common propeller blade is at its 30% position, measured from the propeller root.

CG of propeller blade: $CG_{Blade} = 0.3 \cdot l_{Blade} = 0.237m$

Each propeller blade can be simplified as a mass point m_{Blade} rotating around the propeller axis at a distance r (Fig. 1).

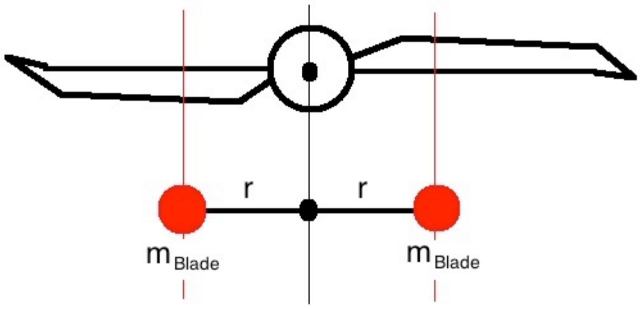

Fig. 1: Simplified model with 2 mass points

Turning radius of propeller blade (mass point): $r = \frac{d_{Spinner}}{2} + CG_{Blade} = 0.327m$

Centrifugal force for a mass point: $F_Z = m \cdot \omega^2 \cdot r$

Maximum rotational speed (MRS): $\omega = 2 \cdot \pi \cdot f = 2 \cdot \pi \cdot \frac{2450\,rpm}{60} = 256.6\frac{1}{s}$

Centrifugal force acting on 1 propeller blade at MRS: $F_Z = m_{Blade} \cdot \omega^2 \cdot r$

$$F_Z = 0.85\,kg \cdot \left(256.6\frac{1}{s}\right)^2 \cdot 0.327m = 18'296\,N$$ [3]

This calculation is conservative, as the entire mass of the propeller blade including the blade root is considered – though the blade root (attached into the propeller hub) doesn't contribute to the centrifugal force on the propeller blade itself.

[3] Alisport mentions an in-service maximum tensile load on the propeller blade of 23 kN (at 2'650 rpm) in its load/endurance reports. There is no further explanation how this load was calculated.

2 Analysis and Discussion

According to CS-22 Subpart J – Propellers, the following requirements should be satisfied:

CS 22.1903 – Instruction manual

Alisport provides its customers with an instruction manual (current edition N0210) that includes:

- Instructions for installation of propeller and its accessories (e.g. electric governor)
- Instructions for functional test before first use
- Maintenance instructions including overhaul period of 300 h
- List of inspections
- Troubleshooting guide

CS 22.1905 – Propeller operating limitations

Propeller maximum rotational speed (MRS): $MRP = 2'450\ rpm$

CS 22.1923 – Pitch control

Possible failure modes of the propeller pitch control:

- Loss of hydraulic fluid/pressure:
  The propeller pitch control mechanism is moved automatically to fine pitch / high RPM by a return spring in the propeller hub. The fine pitch position is limited by a mechanical stop in the propeller hub.
- Erroneous function of electric governor that could lead to propeller pitch runaway:
  The minimum and the maximum permissible propeller pitch positions are both limited by mechanical stops in the propeller hub.
- Complete failure of the electric governor/electro-hydraulic pump:
  In case of loss of electric power supply to the electric governor (or by pulling the corresponding circuit breaker) the electro-hydraulic pump is also shed from the electric power supply and the propeller blade pitch remains likewise at its current position.

CS 22.1935 – Blade retention test

The hub and blade retention arrangement of the propeller must be subjected to a load equal to twice the centrifugal force occurring at the maximum rotational speed.

Twice the centrifugal force at MRS: $\mathrm{F} = 2 \cdot F_Z = 2 \cdot 18'296\ N = 36'592N$

Tensile static test on blade model HS (Doc. #1)

The tensile test (propeller blade) was performed on an electric dynamometer up to blade failure at a load of 167’800 N. The elongation of the blade at this load was equal to approx. 11.5%.

Safety factor of propeller blade: $\boldsymbol{SF_{Blade} = \frac{167'800N}{36'592N} = 4.59}$

Load test blade – hub attachment (Doc. #2)

The tensile test (propeller hub and blade) was performed on an electric dynamometer up to blade attachment failure at a load of 82’000 N. The displacement of the blade at this load was approx. 7 mm.

Safety factor blade – hub attachment: $\boldsymbol{SF_{BladeAttachment} = \frac{82'000N}{36'592N} = 2.24}$ [4]

The load test results satisfy the CS22.1935 requirements without restrictions.

[4] When considering Alisport’s tensile load estimate of 23 kN, the safety factor is still 1.78.

CS 22.1939(b)(1) – Endurance test

According to CS 22.1939 the endurance test should normally be performed by a 50-hours engine-run with maximum rotational speed (MRS) and maximum power rating of the propeller. Alisport performed several comparable endurance tests (as listed below).

Fatigue test of HS blade (Doc. #3)

During this test, a propeller blade was stressed in a combination of static pull test and variable cyclic loads in the orthogonal plane of the blade / plane of the blade (see Fig. 2).

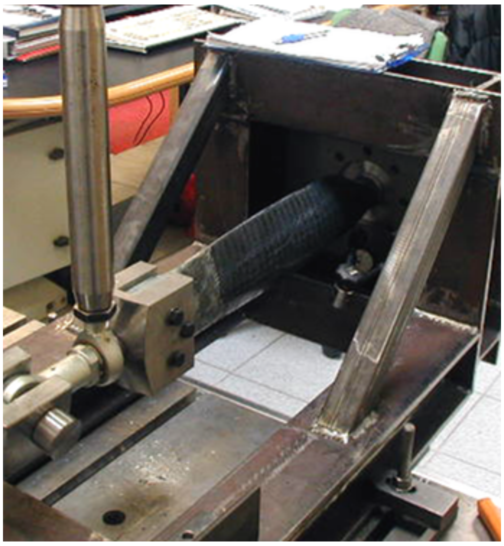

Fig. 2: Test rig for propeller traction / variable load test

Two separate fatigue tests were performed, each lasting 24 hours and 36’450 variable load cycles. The purpose of these tests was to expose the propeller blade to both

- a constant high tensile stress (traction along the propeller blade) to simulate the centrifugal force acting on the propeller blade and
- a variable bending load (orthogonal / parallel to the blade plane) to simulate the aerodynamic forces (and starting impulse force) acting on the propeller blade.

The tests were carried out in “almost static” conditions (where almost static means that the bending loads are varying slowly over time) to evaluate the resistance of the propeller to heavy loads.

The traction along the propeller blade was held constant at 19’900 N during both tests, i.e. with a safety factor of 1.09 for the centrifugal force at MRS.

Test 1: Load orthogonal to the plane of the blade

- Simulation of the aerodynamic force on the blade
- Sinusoidal variation of the load L
- Load amplitude $L = \pm 1200\ N$ and frequency $f = 0.4\ Hz$

Test 2: Load in the plane of the blade

- Simulation of the starting impulse torque and aerodynamic resistance on the blade
- Sinusoidal variation of the load L
- Load amplitude $L = \pm 500\ N$ and frequency $f = 0.4\ Hz$

The integrity of the propeller blade structure and its elastic return (no residual plastic or permanent deformations, no sign of any delamination) at the end of both endurance tests provide evidence, that the propeller blade withstands the centrifugal loads with varying superposed bending loads.

The endurance test on the propeller blade was performed in two steps for a total of 48 hours and 72’900 variable bending load cycles.

Spin test (Doc. #4)

During this test, the propeller was mounted on a propeller test facility shown in Fig. 3. The propeller spin test was performed in 2 steps for a total of 1 hour:

- 30 min. at an average of 2649 rpm (maximum 2680 rpm) and at 75% pitch angle (10°)
- 30 min. at an average of 3054 rpm (maximum 3063 rpm) and at 100% pitch angle (0°)

Fig. 3: Test facility for propeller spin test

***No anomalies, delamination or any other defect were found on the blades and hub.
All screws, pins, etc. did not show any signs of play or wear.***

Endurance test (Doc. #5)

During this test, the propeller was again mounted on the propeller test facility. The test was performed in two steps:

Test 1: The propeller was tested at takeoff power for 5 hours (2’555 rpm).

Test 2: The propeller was tested during 30 cycles of 10 min. each (minimum power for 5 min., then acceleration and operation at takeoff power for 5 min.).

***No anomalies, delamination or any other defect were found on the blades and hub.
All screws, pins, etc. did not show signs of play or wear.***

***The endurance test on the entire propeller (hub and blades) was performed
in two steps for a total of 10 hours.***

CS 22.1941 – Functional test

The worldwide in-service experience of the propeller with the constant-speed electric governor is absolutely trouble-free with no known problems with the propeller and its systems to date (see also chapter 1.1 “In-Service Experience”).

3 Revisions

14.12.2015	Version 1.0	Initial release
22.01.2016	Version 2.0	- New load/endurance test data available, provided by Alisport - Detailed propeller specifications, provided by Alisport - Information about in-service experience with the propeller (UK LAA, Alpi Aviation, Alisport)