THE FASTWING PROJECT, PARAFOIL DEVELOPMENT AND MANUFACTURING

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Abstract

A big size ram-air parachute was designed and manufactured by CIMSA Ingeniería de Sistemas within the frame of the FASTWing Project.
CIMSA Ingeniería de Sistemas has joined efforts together with a consortium of companies from the European Union: Autoflug GmbH - Germany, CESA - Spain, CFD - Norway, DLR – Germany, EADS-ST - Germany, NLR – The Netherlands, for the development of heavy load delivery technologies. The Project was partially financed by the 5th Framework Program of the European Union.
One of the main objectives being to reach a high gliding ratio at high wing loads conditions, the parachute airfoil, plan-form and suspension lines design was performed by means of advanced numerical / empirical prediction and simulation tools. Scaled jump tests, wind tunnel tests and real size drop tests, led to the design validation and successful performance results.

Aerodynamic design

A gliding ratio of 5 was one of the main targets to be reached during the aerodynamic design phase, leading to high lift and low drag force coefficients, within the operation domain.

The airfoil of the ram-air parachute was first selected among different options, by means of an advanced vortex-panel-based aerodynamic tool leading to the aerodynamic configuration of the parachute [1].

The inlet size and position at the parachute leading edge zone, were designed within a wide range of Angle of Attack, ensuring a positive pressure difference cord-wise, throughout the whole airfoil surface, in order to: (a) get a reliable inflation level of all parachute cells, avoiding local collapse; and (b) keep the whole parachute fully inflated without the risk of local wrinkles in the parachute top and bottom surfaces.

Different wings with an area of 160m^2 and an aspect ratio of 4 were analyzed in the aerodynamic trade-off study. Among others, criteria such as aerodynamic performances, pressure distribution at nose and top / bottom surface zones, were assessed for electing the optimal parachute airfoil.

The selected parachute airfoil, so called CIM-2016, is presented in Fig. 1.

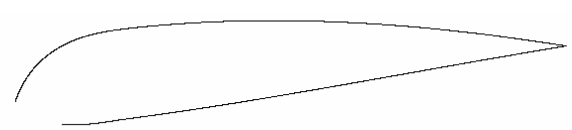

Fig. 1 – Selected airfoil

A trade-off study of different parachute plan-form was performed during the design phase with the aim to reach high glide ratio, flexible control performances and easy manufacturing conditions.
Criteria such as flight performances, maneuverability, packing, deployment, reefing feasibility, stiffness, design accuracy and construction, were assessed during the plan-form election process.

The selected plan form has a tapered structure as presented in Fig. 2 for different opening stages.

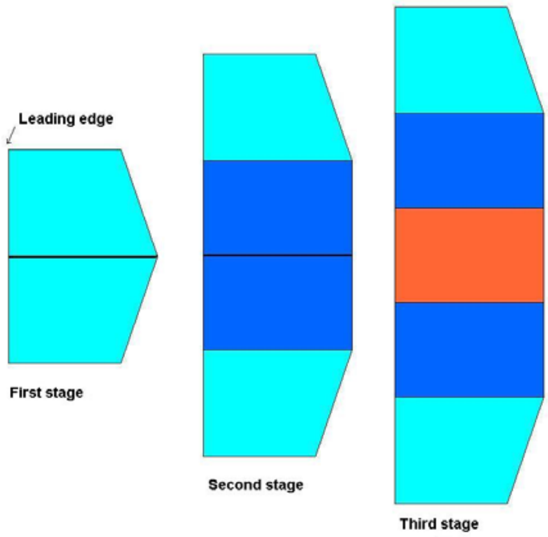

Fig. 2 – Selected plan-form at opening, intermediate and full opening stages

The predicted gliding ratio of the complete system including canopy, suspension lines and payload, was around 4.6.

The gliding ratio as function of the Angle of Attack is presented in Fig. 3

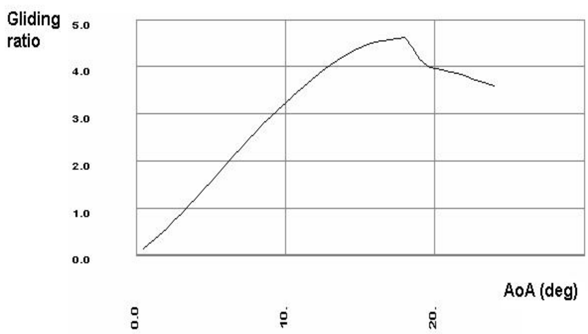

Fig. 3 – Gliding ratio vs. angle of attack

<u>Structural design</u>

A structural analysis was applied within the load operation range (up to 3.5 tons payload mass), based on coupled methodologies involving finite element and Lagrangian-Eulerian fluid dynamic aero-elastic methods [2]. This phase led to: (a) identify the strength performances of the parachute canopy and lines; and (b) select the suitable material for canopy fabric, risers and lines.

Fig. 4 and 5 show the pressure distribution for canopy top and bottom surfaces. High pressure values are identified span wise near the leading edge zone at the top surface canopy and uniform positive pressure is distributed in the rest of the top and bottom surfaces.

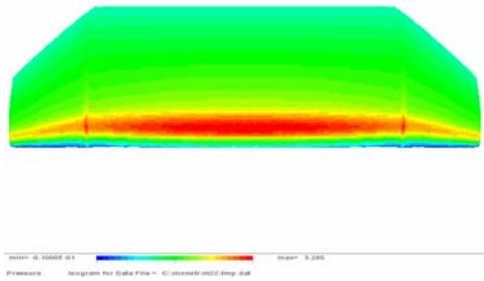

Fig. 4 – Pressure distribution in canopy top surface

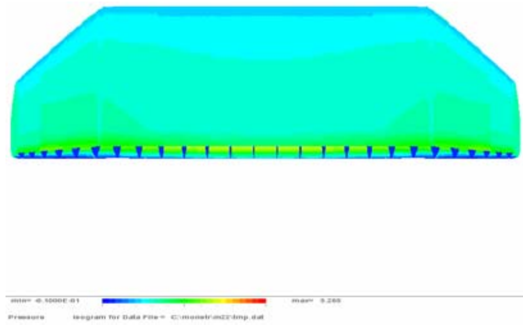

Fig. 5 – Pressure distribution in canopy bottom surface

Based on simulation results, the suspension lines impact on the overall drag of the system was around 60%, consequently an optimized lines attachment distribution in the canopy, as well a cascade configuration were implemented, leading to an important decrease of the suspension lines density.

Strength distribution in suspension lines at extreme load conditions is shown in Fig. 6. Highest strength values are identified in central cells at the leading edge zone.

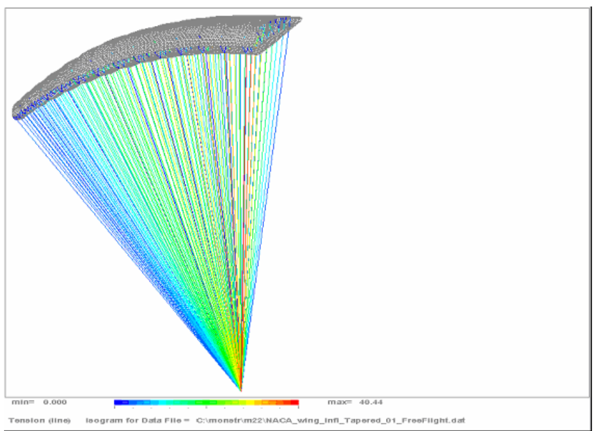

Fig. 6 – Strength distribution in suspension lines

Design validation and tests

The preliminary design was validated by expert jumpers who tested scaled down parachutes of 27.9m^2 area, at different rigging angles configurations. Maneuvers performed by jumpers on the ram-air parachutes led to qualitative and quantitative performances evaluation such as, opening and inflation behavior, flight stability, gliding ratio, resistance to turbulence, guiding and flare effect, as presented in Fig. 7.

Fig. 7 – FASTWing model tested by jumper

A gliding ratio of 4.4 was obtained for the low rigging angle configuration model.

Scaled down models of 12.2m^2 area, were manufactured for wind tunnel tests [3], in order to identify, among others, the aerodynamic performances, the controls deflection aerodynamic effects and the optimal configuration of the ram-air parachute, at reefed and full inflated stages. Wind speed values of 10m/s, 20m/s and 30m/s, as well as dynamic speed sweep from 10m/s up to 30m/s were tested, for different parachute configurations.
The parachute model is presented in Fig. 9 during wind tunnel tests.

Fig. 8 – Wind Tunnel test model inside test section

The complete aerodynamic database of the parachute was obtained within a wide range of Angle of Attack. The optimal rigging angle was identified, leading to high gliding ratio within stable flight conditions.

Measured gliding ratio results L/D as function of lift coefficient C_L are presented in Fig. 9 for different configurations of the parachute, at a wind speed V of 20m/s.
In this figure, configurations A and B correspond to a parachute model having all keels loaded with suspension lines. In configuration C the keels are partially loaded, similar to the real scaled parachute.
The gliding ratio obtained for configuration C is higher than 4.

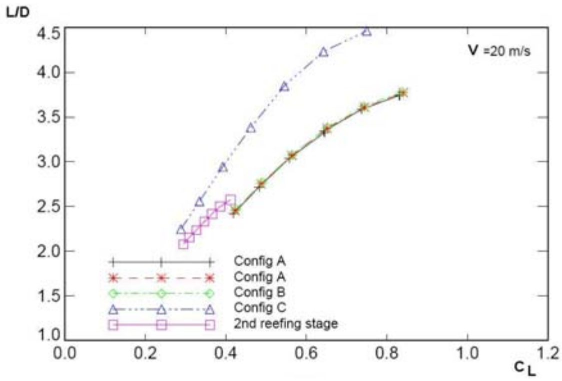

Fig. 9 – Measured gliding ratio in Wind Tunnel tests

The lift coefficient C_L as function of the angle of attack is presented in Fig. 10 for the same wind speed and configurations.

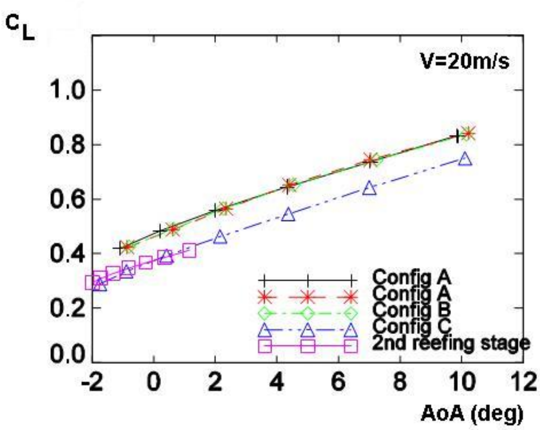

Fig. 10 – Measured lift coefficient C_L as function of angle of attack

Real size tapered ram-air parachute with 27 cells, 160m^2 area and an aspect ratio of 4.03, is currently being tested by means of drop tests performed in Meppen (Germany), by the C-160 Transall Carrier Aircraft from the German Air Force.

Prior to the preparation of the drop test plan, simulations were performed by EADS-ST [4] using software tools for assessing the dynamic behavior of the parachute system.

A wing load range varying from 6kg/m2 up to 20kg/m2 was evaluated during flight tests. Extraction and deployment tests with payloads of 1100kg, 2200kg and 3200kg were successfully performed leading to good performances of the parachute from the point of view of deployment, inflation, flight stability, turn rate, and gliding ratio.

Payload extraction from the aircraft was performed by means of an AS3000 extraction parachute. Payload stabilization phase was performed by a G12D parachute, before the extraction and deployment of the ram-air parachute. The full inflation of the ram-air parachute was obtained after three opening stages resulting from two de-reefing sequences, implemented by Autoflug GmbH [5].
Prior to proceed with the steerable test phase expected to be performed in year 2005, built in asymmetrical brake setting was applied to the ram-air parachute, in order to ensure a controlled descent within the test range. Dummy loads were used for the extraction and deployment series of tests.

A view of the bottom side of the full opened parachute, taken by the on board camera installed on top of the payload, is presented in Fig. 11.

Fig. 11 – Bottom side of the parachute during extraction and deployment tests, taken by the on board camera

A view of the complete system with a suspended payload mass of 2200kg is presented in Fig. 12.

Fig. 12 – View of the complete system during flight, in built in turn configuration

For the steerable tests, the PTD [6] platform payload upgraded by CESA was used.
The guidance, navigation and control software and hardware respectively upgraded by EADS-ST and NLR, were integrated into the platform.

Total flight velocities measured during tests were approximately 12m/s, 19m/s and 22m/s respectively for the different payload mass configurations.

The system gliding ratio obtained from flight tests data analysis, is within the range 2.5 to 6, depending on the time intervals selected during the flight.

Conclusions

The FASTWing project has demonstrated that high gliding performances for heavy loads delivery systems can be reached by using ram-air parachutes, accurately designed and validated by means of wind tunnel and drop testing [7]. The guided heavy load delivery technologies are still to be investigated in order to be used for humanitarian, space and military applications, due to the complex aero elastic structures behavior and parachute characteristics at different flight environments.

References

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