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DESIGN OF A FLYING V SUBSONIC TRANSPORT

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Abstract

Ten years after the initial sketches of the Flying V were made, we intend to give an overview of the development of this concept until the present day. The Flying V is a new concept for an efficient aircraft. It is a pure flying wing which includes a V-shaped passenger cabin. In this work, we describe how the concept developed - from the first drawings, the reasoning behind the concept and the design of the planform geometry, to the introduction of a structural solution for the pressurized cabin, to the design of a family of aircraft, detailed investigations of handling qualities and the interior layout. As of today, the concept promises a 20% lower fuel burn than a conventional reference aircraft on the same mission with the same capacity and the same wingspan, assuming current manufacturing techniques and current engine technology. Research activities on the Flying V have been continuously increasing over the past decade. Projects are ongoing in fields such as aerodynamics, structures and manufacturing, flight dynamics and control, the environmental impact of the design, aircraft integration, noise, and airport operation.

Keywords: flying wing, unconventional aircraft configuration

1. Introduction

This paper intends to chronicle the technical development of the Flying V aircraft concept. Work on this class of airplane began in 2013 at Airbus Future Projects in Hamburg [1]. Figure 1 shows an early sketch of the design. The idea was to arrange two fuselage barrels in the shape of a V and position them inside a wing with a high sweep angle. In doing so, it was aimed to generate a concept which allows to place an efficient structure for the pressurized cabin inside an aerodynamically favorable wing shape. Other intentions were to generate a long lever arm of the control surfaces to the center of gravity of the aircraft, to have small center of gravity excursion for different loading conditions, to position the passenger cabin along the edge of the wing planform to allow for quick evacuation, and to position the engines close to the center axis for a low yawing moment in case of an engine failure.

Since 2016, work on the Flying V has been continued at Delft University of Technology in collaboration with Airbus and KLM Royal Dutch Airlines. Various other collaboration partners have followed in later years.

In the present paper, the development of the Flying V is described in five sections: first, the formulation of the concept, second, its aerodynamic and structural feasibility, third, the design of a family, fourth, flight dynamics and control of the concept, and fifth, the interior design.

2. Formulation of the Flying V Concept

The Flying V concept was substantiated from 2013 to 2015 [2–4]. A three-element wing geometry was introduced, as can be seen in Figure 2. A highly swept inner wing trunk is followed by a transition and outer wing trunk with a lower sweep angle. The transition wing trunk has the same leading edge sweep as the inner wing, and the thin outer wing trunk has the same trailing edge sweep as the transition wing trunk.

Remarkable is the elliptical lift distribution of the stable design, which can be realized with the planform geometry of the Flying V using only moderate wing twist and without using reflexed camber

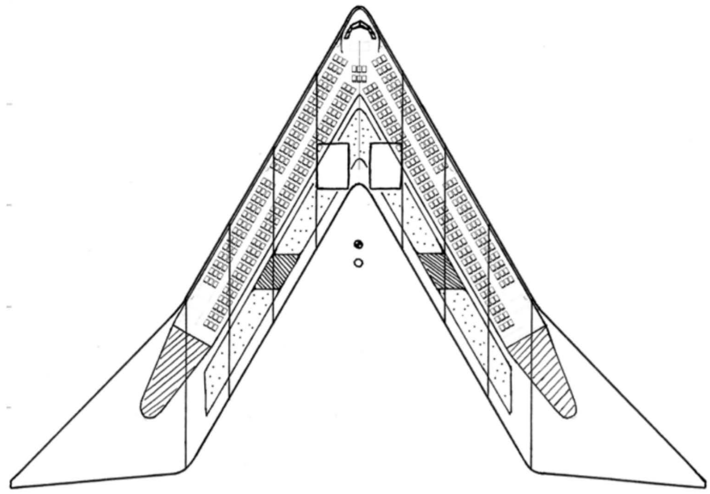

Figure 1: Early sketch of the Flying V from 2013 [1]. Fuel is positioned behind the pressurized passenger cabin (dotted region). Cargo is positioned more towards the outside of the wing (streaked region).

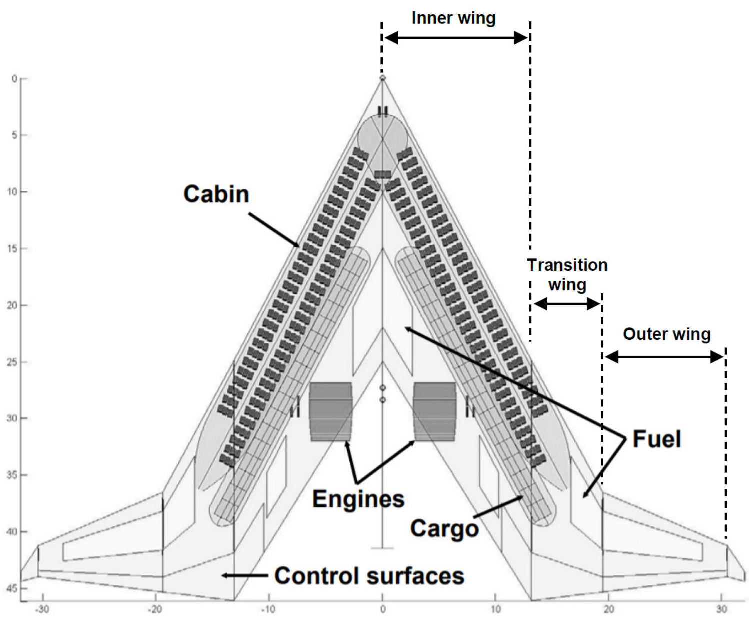

Figure 2: Flying V aircraft configuration from 2014 [4].

lines [4]. In order to demonstrate these characteristics a radio controlled model with a wingspan of 1.3m was built and flown in 2014, see Figure 3. Glider flights without engines and several powered flights with engines where performed demonstrating good handling qualities.

The 2015 Flying V, see Figure 4, was designed with a wingspan of 65m for 315 passengers in a two-class layout, and a cruise speed of Mach $= 0.85$. The Airbus A350-900 has the same wingspan, capacity and cruise speed and was chosen as a reference aircraft. In a reference two-class configuration, the airplane was designed to transport 315 passengers over a range of 15,000 km. Wing sections with a maximum thickness to chord ratio of 13% where used on the highly swept thick inner wing of the Flying V. The integration of an A320-like cabin surrounded with a pressurized structure of almost circular cross section left room inside the wing to store cargo in a second pressurized tube. For structural efficiency, engines where positioned directly over the landing gear.

Preliminary estimations of the aerodynamic performance and the weight of the aircraft indicated a 10% higher L/D and a 2% lower empty weight of the Flying V concept compared to the A350-900 reference aircraft [4]. Additional incentives found for the concept were the compactness and simplicity

Figure 3: First flight of the glider version of the Flying V demonstrator model in Berlin on February 28, 2014 (left), first flight of the powered version of the demonstrator model in Hamburg on April 13, 2014 (right) [4].

of the configuration (less parts, no high-lift devices, no fairings, straight lines) and partial shielding of the engines from the ground leading to less noise.

3. Aerodynamic and Structural Feasibility

The aerodynamic and structural feasibility of the Flying V was assessed in more detail between 2016 and 2018. A key to the further development of the concept was the introduction of an oval-fuselage cross-section for the pressurized cabin. The oval fuselage cabin was introduced by Vos et al. in 2012 as a solution to the non-circular blended-wing-body cabin [5]. The oval cross-section of the Flying V cabin consists of piece-wise circular arcs that are reinforced by a trapezoidal structure as shown in Figure 5. This structure prevents out-of-plane loads and can therefore be made relatively efficient [6]. The lower horizontal member of the trapezoidal substructure doubles as the passenger floor, allowing ten seats abreast with two aisles. The poles that are located close to the side walls are loaded in tensions when the cabin is pressurized, while the floor and ceiling members are loaded in compression. This configuration assumed the cargo compartments relocated to their original position at each end of the main deck and the fuel behind the passenger compartment (see Figure 1).

Using the oval-fuselage cross-section of the wing, an updated parametric model of the Flying V was constructed using the same top-level requirements as in [4]. An aerodynamic optimization of the geometry was performed based on the Euler equations resulting in a 25% higher lift-to-drag ratio for the Flying V compared to the NASA common research model [7]. An image of the optimized

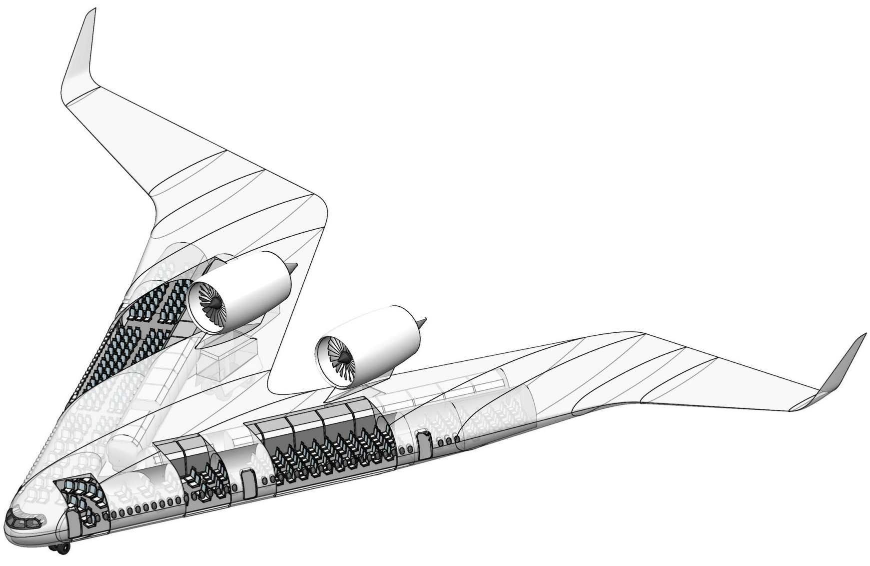

Figure 4: CAD model of the Flying V from 2015 [4].

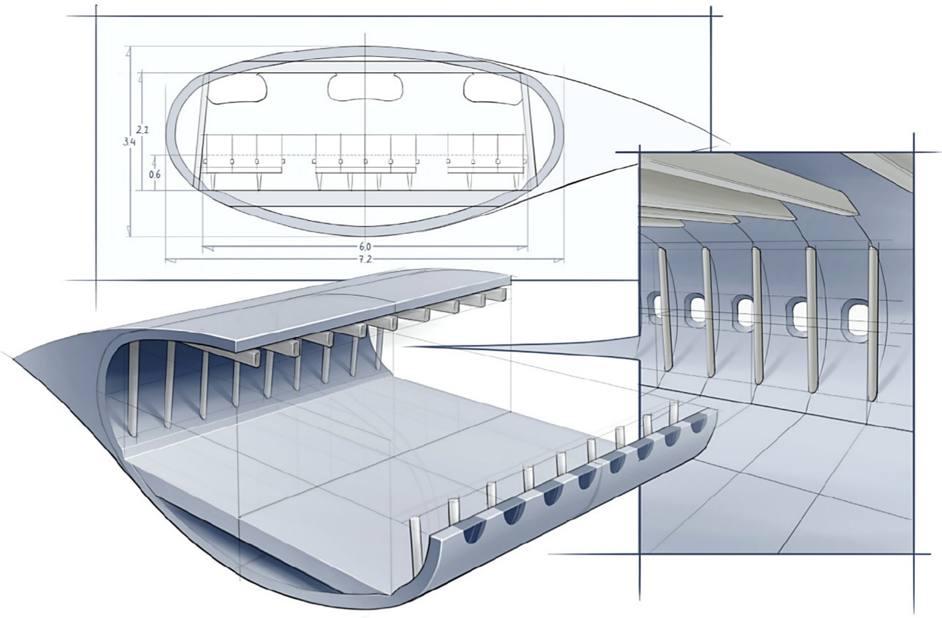

Figure 5: Oval fuselage section of the Flying V. [27]

Flying V wing shape and the Mach contours on the upper surface is displayed in Figure 6. This shows that the outboard wing has typical transonic pressure distribution, while the inboard wing shows an area of high Mach numbers at the intersection between the two fuselage arcs. In Ref. [8], a feasible region for the engine location was identified based on Euler CFD computations to minimize adverse aerodynamic interference with the wing while respecting regulations regarding inter-engine separation.

Preliminary parameterization of the structure of the Flying V was performed by Van der Schaft at the Airbus Future Projects Office [9]. An estimation of the structural weight was subsequently performed by Claeys in Ref. [10] and showed a 17% decrease in FEM weight compared to an A350-like aircraft based on an automated structural sizing algorithm coupled to an FEM solver. In these two studies, fourteen different load cases were investigated including a 2.5g pull-up maneuver, a -1g maneuver, a taxi-bump during take-off, braking, and a side gust. Some cases were tested at various loading scenarios and both with and without pressurization loads. Sizing was done based on a maximum stress allowable assuming an all-aluminum structure for both the reference aircraft as well as the Flying V.

The results from the aerodynamic analysis and structural analysis were subsequently used in a

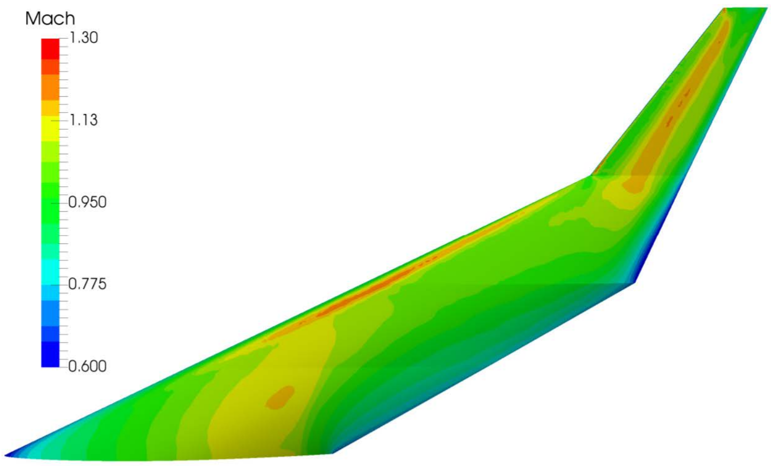

Figure 6: Optimized Flying V wing shape for cruise flight from [7]. Mach contours are displayed over the upper surface of the wing for Mach 0.85.

rudimentary design synthesis process to estimate the effect of these improvements on the fuel burn of the aircraft. This resulted in an estimation of 20% reduced fuel burn for the Flying V compared to a modern twin-aisle aircraft with the same top-level aircraft requirements, the same technology assumptions, and the same propulsion system. This double-digit improvement sparked the incentive to continue to investigate the concept and analyze a variety of aspects including flight dynamics and control, interior design, and further detailing of the aerodynamic outer mold line to improve the aerodynamic performance.

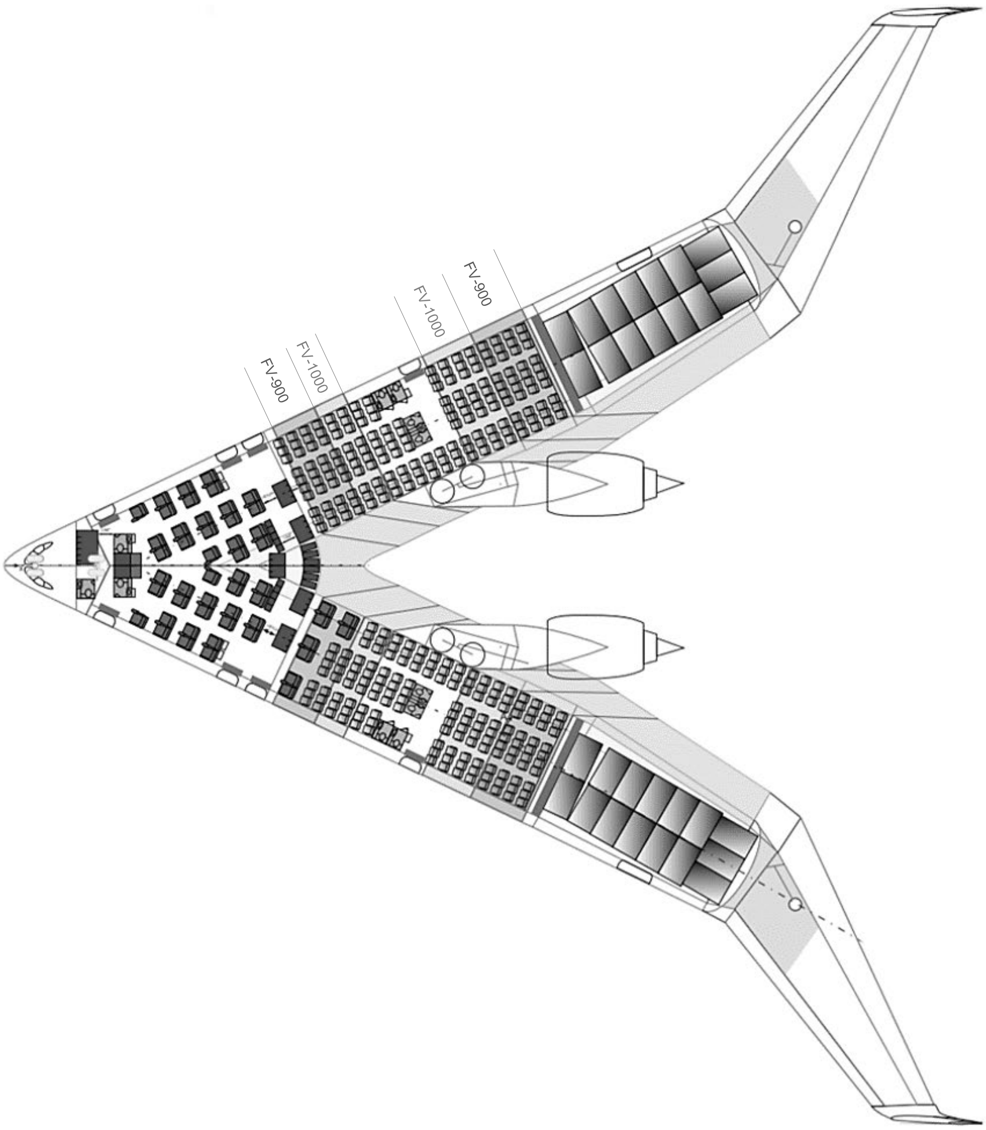

Figure 7: 2020 iteration of the Flying V aircraft concept. Displayed here is an image of a FV-1000 with a wingspan of 65m seating 378 passengers in a two class layout. Taking out the FV-1000 wing trunks creates the FV-900 version. Further removing the FV-900 wing trunks creates the FV-800 version.

4. Design for Family

The design of the Flying V aircraft concept, with its characteristic planform geometry and only moderate wing twist (see [4]), allows for a simple family concept by stretching and shrinking the highly swept inner wing section. In 2019, the iteration of the Flying V was updated to allow for such a family of aircraft to be constructed. Hillen defined a new parameterization for the Flying V allowing for the stretching of the inboard part of the wing [11]. While the original Flying V was designed for 315 passengers, in this new parameterization 378 passengers were fitted in a standard two-class configuration (52J, 326Y)[1] along with 34 LD4 containers located behind the cabin on the same deck. The

[1] A 55” seat pitch was assumed for business class (J) and 32” for economy class (Y).

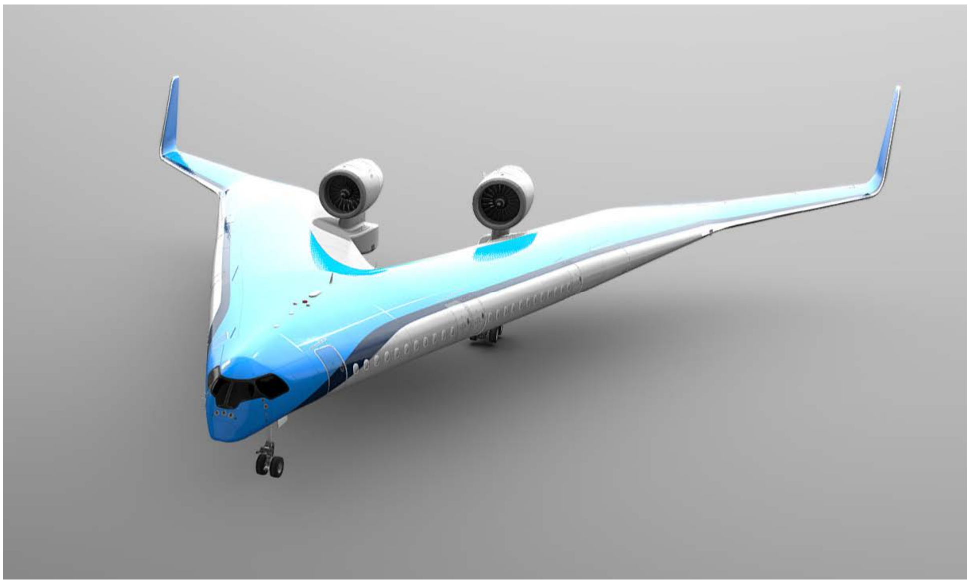

Figure 8: Artist impression of the Flying V by Studio OSO.

resulting Flying V design mimicked the A350-1000 in terms of payload capability as well as range performance (see Figure 7). Oosterom and Vos [12] performed a multidisciplinary design optimization for the simultaneous design of three aircraft family members. The typical cabin arrangement for the three aircraft was set to 293 seats, 328 seats, and 378 seats, respectively for the -800, -900, and -1000 member. While satisfying 100% commonality with the largest aircraft, a reduction in fuel burn of 22% and 20% compared to the A350-900 and A350-100 aircraft was predicted for the same mission range and payload. The aircraft family was geometrically achieved by taking out wing trunks of constant cross section ahead of and behind the central wing trunk (see Figure 7). The takeoff mass of the Flying-V family members was predicted to be 185 tonnes, 234 tonnes and 266 tonnes, respectively.

To improve the intuitive design of the Flying V, an artist impression of the Flying V external and internal geometry was made including details of cabin design, the cockpit and flight deck layout, and the integration of engine and undercarriage. This design could be examined using VR goggles and allowed the designers to query various stakeholders about the design. This included the design of the flight deck and windows from pilots and the various interior design options. An image of the artist impression of the Flying V can be seen in Figure 8.

5. Flight Dynamics and Control

It was shown in [4] that the Flying V could be flown with adequate handling qualities. Yet, geometry modifications of the Flying V warranted further investigation into the flight dynamics and control aspects of the vehicle. This section details the research activities and main findings regarding this aspect of the Flying V.

5.1 Wind tunnel tests and scaled flight testing

Based on the optimized geometry of Faggiano [7], Palermo and Vos made a design for 3-meter span geometrically-scaled version of the Flying V that was 4.6% of the full-scale aircraft [13]. As it was anticipated that the highly-swept, blunt-nosed wing could have unexpected stall behavior, a semi-wing wind-tunnel model was constructed to be tested in the TU Delft Open Jet Facility. This semi wing was mounted to a turntable and 6-component force transducer to measure the aerodynamic loads on the wing at various speeds and angles of attack. An image of the experimental setup is displayed in Figure 9.

The results showed that the wing could attain a maximum lift coefficient of $C_{L_{\max}} = 1.02$ at an angle of attack of $\alpha = 35^{\circ}$ with nonlinear effects starting as early as $\alpha = 10^{\circ}$. The pitching moment was negatively correlated to the angle of attack up to $\alpha = 19^{\circ}$. After this, a pitch-break occured, making the aircraft statically unstable about the moment reference point. The effectiveness of the elevons was

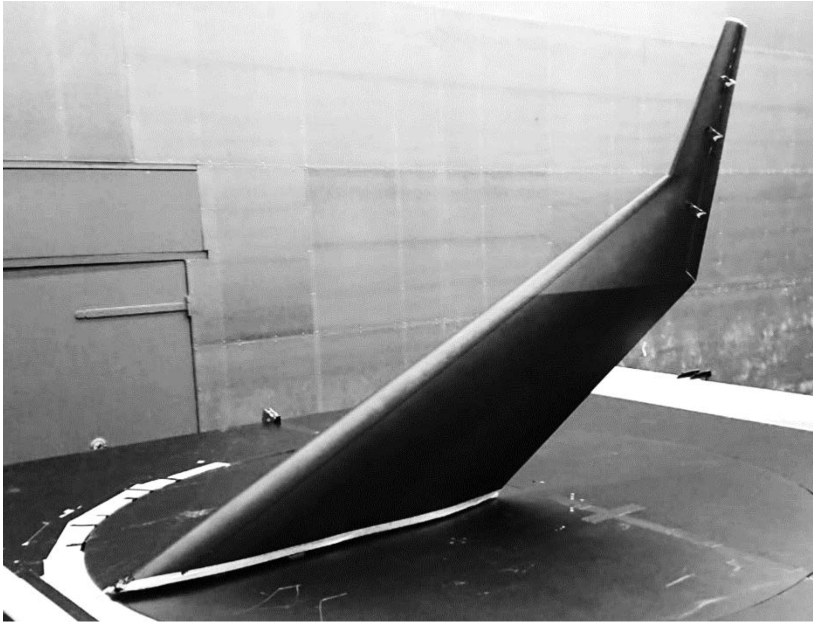

Figure 9: Experimental setup of a 4.6% Flying V half model in the TU Delft open jet facility. [7]

found to be virtually independent of the angle of attack. Based on these findings an initial estimation for the allowable center-of-gravity excursion was made to ensure the aircraft would be longitudinally stable and trimmable. Smoke visualizations, oil flow visualizations and tufts were subsequently used by Viet to demonstrate that beyond $\alpha = 10^{\circ}$, the wing developed strong vortices originating at various locations on the wing changing in number, position and strength depending on the angle of attack [14]. Similar behavior of the flow around the Flying V at high angles of attack was described for lower Reynolds numbers using high fidelity numerical simulations in [15]. It was observed that at high angles of attack characteristic vortex structures originate, particularly from the region of the highly swept trailing edge of the Flying V and intermingle in a characteristic fashion with the main flow around the wing. Complex flow beahaviour was observed and described in the region further to the outside where the outer wings attach to the inner wing and continue at a lower sweep angle. Further work is currently ongoing to develop a full understanding of the vortex patterns of the unconventional Flying V shape at high angles of attack over a wide Reynolds number range.

An aerodynamic model based on the wind tunnel experiments at TU Delft was identified by Ruiz Garcia [16]. It was demonstrated that the model identification could successfully be achieved using parameter identification. The estimated models were validated against a partition of the experimental data that was not used for the estimation, which demonstrated that an adequate model fit and good prediction capabilities were attained. The same technique was then used to identify the aerodynamic model of the scaled flight testing article, which was in the process of being built at the time these results were obtained.

Another unknown was the effect the engine thrust setting would have on the aerodynamic performance of the wing. As a strong aerodynamic interaction between the engine and the wing could potentially lead to undesirable flight dynamics behavior, the installation effects of the engine were studied experimentally using the same semi-wing that had been used by Palermo, Viet and Ruiz-Garcia. Van Empelen demonstrated that the interference effects of thrust and nacelle on lift and pitching moment were of the same order of magnitude as the effect of superpositioning the contributions of the isolated engine and the wing [17]. However, while the interference effects were not to be neglected, it was concluded that the installation of the engine would not negatively influence the stability and controlability properties of the vehicle.

A sub-scale flight test article of the Flying V with a span of 3.06m was built and flown in 2020. Weighing close to 25kg, the airplane had two electric ducted fan engines, each producing 60N of static thrust resulting in a (static) thrust-to-weight ratio of almost 0.5. The ariplane had a retractable landing gear. While the outboard wing had three individually controlled control surfaces, they were

Figure 10: First flight of the 4.6% Flying V sub-scale flight testing model, Fassberg Air Base, July 14, 2020.

operated as one elevon for mixed pitch and roll control. Yaw control was achieved by means of rudders in the vertical tail plane. A driving constraint for the control surface sizing was the constraint to rotate the airplane about the main-landing-gear axle prior to lift-off at an acceptable taxi speed. To measure the accelerations, angle of attack, and angle of sideslip of the aircraft during the flight an Aeroprobe Voyager data computer connected to a 5-hole pitot was employed. An image from the first test flight is displayed in Figure 10.

While the first flight was successful in terms of demonstration, most of the research flight testing took place in the summer of 2021. System-identification techniques were employed to extract the state-space model of the airplane. Inertia estimations were performed by means of a detailed CATIA drawing of the airplane coupled with a meticulous weighing of the individual components. Based on this, the aerodynamic model could be derived and all the stability and control derivatives could be extracted [18]. The lift and pitching moment coefficients from the test flights and from the wind

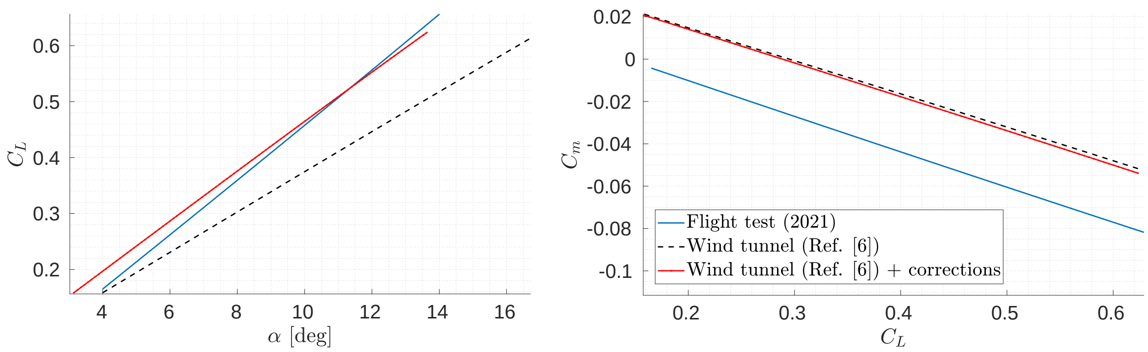

Figure 11: Lift and pitching moment coefficients from the test flight campaign and from the wind tunnel experiments. [18]

tunnel experiments from a clean half wing are displayed in Figure 11 with and without wind-tunnel corrections. The pitching moment from the flight test shows a constant shift with respect to the wind tunnel results. This can be explained by the landing gear drag in flight as it provides a negative pitching moment.

5.2 Handling Quality Assessment

Handling qualities of the Flying V have been further investigated and compared with the reference aircraft by Cappuyns [19]. This analysis, predicted that the Flying V has favorable handling qualities in general. Yet, the results - which were obtained with control derivatives obtained with a Lattice Vortex Method - also predicted that directional control was lacking to perform a cross-wind landing. Based on the work of Cappuyns and subsequent aerodynamic simulations by Airbus GmbH, a flight dynamic model of the Flying V was developed by Van Overeem et al [22]. It was shown that the bare-airframe of the Flying V possessed a mildly unstable Dutch-roll mode at approach speed, which was shown to be damped when a yaw damper was applied. Furthermore, it was shown that during the majority of the flight envelope the bare airframe was predicted to have Level 1 Handling Qualities.

A wind-tunnel campaign performed by Johnson on a 4.6%-scale semi-wing model showed a 50% reduction in yaw control power when the angle-of-attack was increased from 0 to 20 degrees [20]. This reduction, which had also been observed in the simulations by Cappuyns [19], was attributed to the 'sweep effect' of the rudder hinge line. The low lift-curve slope of the Flying V resulted in a high angle-of-attack at stall. As the effective maximum lift coefficient was expected to occur at an angle-of-attack of 20 degrees, yaw control by means of the two winglet rudders was deemed to be insufficient. Nolet experimentally tested various split-flap configurations replacing the most outboard elevon [21]. It was demonstrated that such a "drag rudder" could improve the yaw control power by 150% at the assumed stall angle-of-attack of $\alpha = 20^{\circ}$.

To test the evaluation of the handling qualities, Vugts et al used the flight dynamics model to do piloted simulations in the SIMONA research simulator of TU Delft. Pilots were asked to perform pitch tracking and flight-path tracking tasks and evaluate the performance in cruise conditions on the Cooper-Harper scale [23]. Two control allocation schemes for longitudinal control were devised based on offline calculations. For the default control allocation (i.e. all control surfaces acting as elevators), pilots indicated the pitch-attitude control to be Level 1 while the flight-path control was Level 2. While a new control allocation improved the performance of the pilots during the flight-path tracking task, its lowered control authority was too much for most pilots to rate it at Level 1.

A later study [24] demonstrated that the current iteration of the Flying V behaves similar to a conventional aircraft in terms of its lateral eigenmodes. Here, phugoid, short period, spiral, roll convergence, and dutch roll modes where all found to be stable, albeit the dutch roll mode was found to be less damped than on a conventional aircraft. In some approach conditions, the current iteration of the bare airframe Flying V was found to lack control authority to comply with present certification regulations. Yet again, these results were once more obtained based on control derivatives from an inviscid model. Complex vortex patterns observed in previous studies [14, 15] were not yet taken into account in these studies. Favourable handling qualities experienced by pilots of scaled flight testing articles of the Flying V and viscous numerical simulations showing complex vorticies on the Flying V suggest a considerable influence of these flow phenomena on the control derivatives at higher angles of attack. These matters along with the impact of the drag rudders will be addressed in future studies.

6. Interior Design

Various interior concepts for the Flying V have been proposed in recent years [25–28]. Seating layouts for the oval cabin (Figure 5) range from traditional layouts (Figure 7) to alternate seating arrangements.

One unique aspect of the Flying V cabin is the orientation of the seats. Regulations stipulate that with a normal seat belt, a passenger seat should not be rotated more than 18 degrees with respect to the flying direction. As the main cabin is rotated over 26 degrees, an 8-degree seat rotation is required to comply with this requirement. However, this orientation also allows one to stagger the seats while rotating them over the full 26 degrees. This was tested in a mock-up of the Flying V cabin in 2019 and 2020 [28] as one of four new interior concepts (see Figure 12). Participants of

Figure 12: Staggered seats may be added to the cabin of the Flying V to allow passengers more privacy while they sit in the direction of flight. [28]

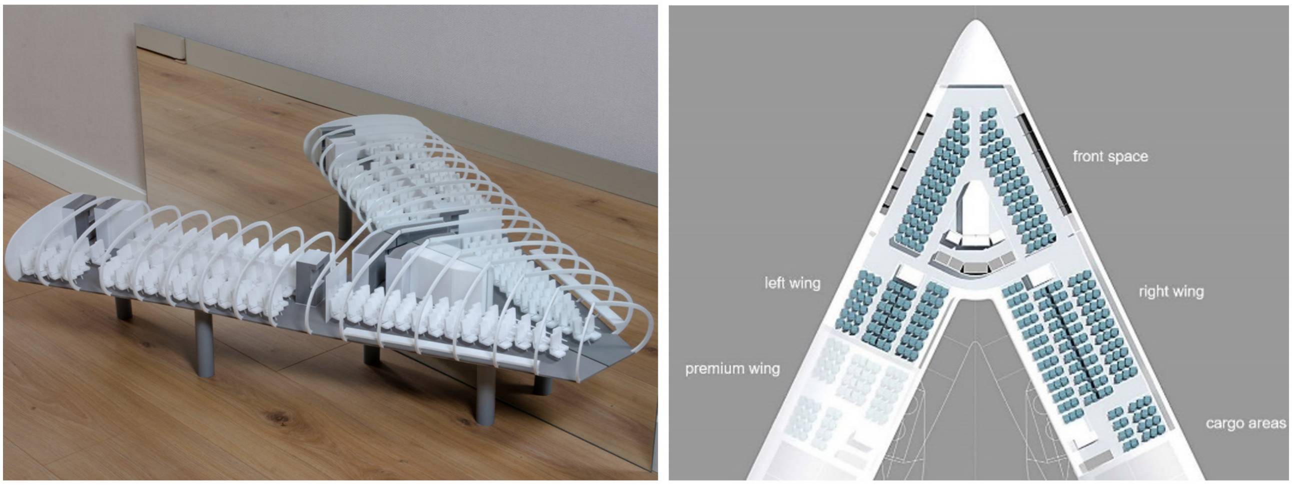

Figure 13: View of an alternative cabin concept for the Flying V. A model is displayed on the left, a schematic view is displayed on the right. [27]

the experiment reported that they liked the 26-degree staggered seat because elbows and shoulders were no longer touching giving them a sense of more privacy.

Chung pioneered in the interior design of the Flying V and presented a very innovative design without cargo compartments but dividing the entire floor surface into different areas: a lounge area, a working area, and a resting area where people could sleep [25]. Wamelink revisited the interior design in 2021 and designed a somewhat more traditional cabin with large walking aisles next to the leading edge of the wing [27] (see Figure 13 and Figure 14). The large aisles would allow passengers to move around the cabin during the flight, improving their comfort level. Wamelink introduced various seating areas, where some seats were rotated over 26 degrees to improve privacy, while other seats were only rotated by 9 degrees, allowing more cosy side-by-side seating.

Evacuation for the Flying V cabin and the A350 reference cabin was modelled in Refs. [29–31]. Results showed similar evacuation times for both aircraft configurations. The dimensions of the aisle connecting the cabin at the rear kink in the center of the V were found to be of particular importance for an efficient evacuation process. The double doors on both sides of the plane and some additional space in the cabin in front of them (see Figure 7 and Figure 13) were found to have a positive effect on the evacuation process for several closed-door configurations which were tested. Boarding and de-boarding of the Flying V was investigated in [32] showing reduced times for the Flying V when compared to conventional configurations due to the presence of four aisles that can be used simultaneously by passengers. Further ground handling procedures were investigated in [33]. Results showed that the Flying V complies well with the infrastructure on present airports. This topic is currently investigated in more detail in collaboration with the industry.

Figure 14: Interior view for the alternative floorplan concept displayed in Figure 13. [27]

7. Conclusion and Outlook

Over the past decade, research on the Flying V configuration has demonstrated that the Flying V is both a viable and more energy-efficient alternative to tube-and-wing aircraft. Many aspects of this configuration have been studied including its aerodynamic properties, its structural design and associated weight, its handling qualities and its interior design. While in each of these aspects challenges have arisen, none of them have been identified as potential showstoppers for the concept. Given the fact that the Flying V is essentially a multi-functional wing surface, its design is complex and requires the integration of all aeronautical disciplines. However, the airframe itself is simple: no high-lift devices and only hinged control surfaces. The lower wetted area, increased effective span, and improved span loading yield a 20% reduction in energy consumption.

Various research projects on the Flying V configuration are presently ongoing in fields such as aerodynamics, structures and manufacturing, flight dynamics and control, aeroelasticity, environmental impact, and airport operation. Examples are investigations of winglet integration and rudder deflection, optimization of the outer-mold line to improve the aerodynamic efficiency, analysis of spoilers, preliminary design of engine and landing gear integration, bird strike investigation for the leading-edge windows, cockpit design and flight deck integration, testing of take-off and landing handling qualities in the simulator, assessment of the noise signature, flight performance investigation, and simulation of ground handling processes. A new parameterization of the Flying V is currently being created to account for the findings of previous research projects and serve as a reference for future studies.

Acknowledgements

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References

[1] Benad J. Luftfahrzeug. *Patent application DE102014201040A1, Airbus*, 2014.
`https://register.dpma.de/DPMAregister/pat/PatSchrifteneinsicht?docId=DE102014201040A1`

[2] Benad J. The Flying V: A new aircraft configuration. *Presentation, Seminar für Mechanik, Technische Universität Berlin*, 2015.
`https://www.jbenad.com/news/2015/2/4/flyingv`

[3] Benad J. Design of a commercial aircraft for high-subsonic speed as a flying wing configuration. *Technical report, Airbus*, 2015.
`https://www.jbenad.com/flyingv-technical-report`

[4] Benad J. The Flying V - A new aircraft configuration for commercial passenger transport. *Deutscher Luft- und Raumfahrtkongress, Rostock*, 2015.
`https://doi.org/10.25967/370094`

[5] Vos R, Geuskens F J J M M and Hoogreef M F M. A new structural design concept for blended wing body cabins. *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, p 1998, 2012.
`https://doi.org/10.2514/6.2012-1998`

[6] Hoogreef M F M and Vos R. The Oval Fuselage; A new Structural Design Concept for Blended-Wing-Body Cabins. *Proceedings of RAeS 3rd Aircraft Structural Design Conference*, pp 553-567, 2012.
`https://www.proceedings.com/19332.html`

[7] Faggiano F, Vos R, Baan M and van Dijk R. Aerodynamic design of a Flying V aircraft. *17th AIAA Aviation Technology, Integration, and Operations Conference*, p 3589, 2017.
`https://doi.org/10.2514/6.2017-3589`

[8] Rubio Pascual B and Vos R. The effect of engine location on the aerodynamic efficiency of a Flying-V aircraft. *AIAA Scitech 2020 Forum*, p 1954, 2020.
`https://doi.org/10.2514/6.2020-1954`

[9] van der Schaft L. Development, Model Generation and Analysis of a Flying V Structure Concept. *Master thesis, Delft University of Technology*, 2017.
`http://resolver.tudelft.nl/uuid:d9c9c02f-d67a-4e3c-93a7-eb20ed67cd03`

[10] Claeys M. Flying V and Reference Aircraft Structural Analysis and Mass Comparison. *Master thesis, Delft University of Technology*, 2018.
`http://resolver.tudelft.nl/uuid:ee7f2ecb-cdb6-46de-8b57-d55b89f8c7e6`

[11] Hillen M. Parametrisation of the Flying-V Outer Mould Line. *Master thesis, Delft University of Technology*, 2020.
`http://resolver.tudelft.nl/uuid:f4863ae4-2792-4335-b929-ff9dfdb6fed5`

[12] Oosterom W. Flying-V Family Design. *Master thesis, Delft University of Technology*, 2021. (paper submitted for AIAA Aviation)
`http://resolver.tudelft.nl/uuid:9e8f9a41-8830-405d-8676-c46bf6b07891`

[13] Palermo M and Vos R. Experimental aerodynamic analysis of a 4.6%-scale Flying-V subsonic transport. *AIAA Scitech 2020 Forum*, p 2228, 2020.
`https://doi.org/10.2514/6.2020-2228`

[14] Viet R. Analysis of the flight characteristics of a highly swept cranked flying wing by means of an experimental test. *Master thesis, Delft University of Technology*, 2019.
`http://resolver.tudelft.nl/uuid:90de4d9e-70ae-4efc-bd0a-7426a0a669c3`

[15] Benad J. Development of a numerical flow channel with the Lattice Boltzmann method and application to highly swept wings at high angles of attack. *Doctoral thesis, Technical University Berlin*, 2022.
`https://doi.org/10.14279/depositonce-15208`

[16] Ruiz Garcia A, Vos R and de Visser C. Aerodynamic model identification of the Flying V from wind tunnel data. *AIAA Aviation 2020 Forum*, p 2739, 2020.
`https://doi.org/10.2514/6.2020-2739`

[17] van Empelen S and Vos R. Effect of Engine Integration on a 4.6%-Scale Flying-V Subsonic Transport. *AIAA Scitech 2021 Forum*, p 0939, 2021.
`https://doi.org/10.2514/6.2021-0939`

[18] Ruiz Garcia A, Brown M T H, Atherstone D, van Arnhem N and Vos R. Aerodynamic Model Identification of the Flying V from Sub-Scale Flight Test Data. *AIAA Scitech 2022 Forum*, p 0713, 2022. https://doi.org/10.2514/6.2022-0713

[19] Cappuyns T. Handling Qualities of a Flying V Configuration. *Master thesis, Delft University of Technology*, 2019. http://resolver.tudelft.nl/uuid:69b56494-0731-487a-8e57-cec397452002

[20] Johnson, N. Effect of Winglet Integration and Rudder Deflection on Flying-V Aerodynamic Characteristics. *Master thesis, Delft University of Technology*, 2021. http://resolver.tudelft.nl/uuid:b664ae03-846f-4ad3-849a-c081a32260ad

[21] Nolet, S. Improving the Flying V Directional Control Power by the Implementation of Split Flaps. *Master thesis, Delft University of Technology*, 2022. http://resolver.tudelft.nl/uuid:18847b0d-597d-4539-968f-ebc8a14c905e

[22] van Overeem S, Wang X and van Kampen E J. Modelling and Handling Quality Assessment of the Flying-V Aircraft. *AIAA Scitech 2022 Forum*, p 1429, 2022. https://doi.org/10.2514/6.2022-1429

[23] Vugts G Stroosma O Vos R Mulder M Simulator Evaluation of Flightpath-oriented Control Allocation for the Flying-V. *Proceedings of AIAA SciTech (submitted)*, 2023.

[24] Joosten S. Stroosma O Vos R Mulder M Simulator Assessment of the Lateral-Directional Handling Qualities of the Flying-V. *Proceedings of AIAA SciTech (submitted)*, 2023.

[25] Chung I. Cabin Interior Design of the Flying V. *Master thesis, Delft University of Technology*, 2018. http://resolver.tudelft.nl/uuid:44843121-ece2-4394-a94d-03da5bc563b3

[26] Lam T. Aircraft Interior Systems for the Future Onboard Services in the Flying-V. *Master thesis, Delft University of Technology*, 2020. http://resolver.tudelft.nl/uuid:68dec7a4-baef-4ea8-bf35-c00d4b95798b

[27] Wamelink L. Flying-V interior: Floorplan design for improved passenger comfort. *Master thesis, Delft University of Technology*, 2021. http://resolver.tudelft.nl/uuid:183180db-b1c0-44a9-aa68-3215f7a6247c

[28] Vink P, Rotte T, Anjani S, Percuoco C, and Vos R. Towards a hybrid comfortable passenger cabin interior for the Flying V aircraft. *International Journal of Aviation, Aeronautics, and Aerospace*, Vol. 7, No. 1, 2020. https://doi.org/10.15394/ijaaa.2020.1431

[29] Gebauer J and Benad J. Flying V and Reference Aircraft Evacuation Simulation and Comparison. *arXiv preprint arXiv:2102.06502*, 2021. https://arxiv.org/abs/2102.06502

[30] Hellmann R. Evacuation simulation of a Flying V aircraft using Cellular Automata. *Bachelor thesis, Technical University Berlin*, 2020. https://doi.org/10.14279/depositonce-15765

[31] Franosch G. Flying V and reference aircraft evacuation simulation and investigation of cabin layouts. *Master thesis, Technical University Berlin*, 2021. https://doi.org/10.14279/depositonce-15737

[32] Isgro F. Fuselage Design Studies to Improve Boarding Performance of Novel Passenger Aircraft. *Master thesis, Delft University of Technology*, 2020. http://resolver.tudelft.nl/uuid:d6acfd90-b02c-4d22-8463-d56b6d52480e

[33] Hinsch S. Untersuchung von Abfertigungsaspekten einer Nurflüglerkonfiguration an bestehenden Flughafeninfrastrukturen - Am Beispiel des „Flying V“. *Bachelor thesis, Hochschule Bremen*, 2018.