# THE RACER: MANUFACTURING AND TESTING

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## Abstract

The RACER represents a demonstrator of an innovative and unique high-speed rotorcraft which is developed at Airbus Helicopters in the frame of the European CleanSky2 initiative in co-operation with multiple research, development, and manufacturing partners all over Europe. The RACER is planned to have its first flight by mid of 2022. This paper first gives a brief global introduction of the high-speed concept, highlighting the main outstanding characteristics in terms of mission performance, aerodynamics ad structures. Furthermore, an overview of the airframe structural composition is presented with a special focus on the basic structural arrangement of the three main components of the aircraft: the joined wings, the tail and empennage, and the main fuselage as largest integrative element of the vehicle. The main component`s description includes an insight on design and production details, as well as testing and substantiation approaches and addresses some of the major innovation topics. Some pictures reflect the assembly and production status at the date of the paper submission.

## 1. THE RACER

### 1.1 The Clean Sky Program

The RACER demonstrator is being developed as part of the European research program CleanSky2 within the platform for innovative aircraft demonstrators (IADP). Clean Sky is the largest European research program for the development of innovative cutting-edge technology to increase sustainability, cost-efficiency and mission performance as well as to reduce aircraft emissions. It is financed from the EU program "Horizon 2020" and contributes to the promotion of European cooperation within aircraft industry and research. The aim of the IADP platform is to develop new types of vertical flight capable aircraft that close the mobility gap between traditional fixed-wing aircraft and helicopters.

The RACER demonstration project takes place as part of a large European partnership led by AIRBUS Helicopters (Fig. 1). It includes eight main partners and eighteen secondary partners. In this program, the partnership offers European companies, research institutions and universities the opportunity to work on a future-oriented aircraft concept and to advance their own innovations up to a high technology maturity level. The definition of the overall architecture, the dynamic system and the aeromechanical and performance definition, the structural conceptual design and pre-analysis, as well as the overall assembly are some of the technical contributions within the RACER project made by AIRBUS Helicopters. The detailed design and construction of the fuselage is carried out by the Romanian consortium RoRCraft (INCAS National Institute for Aerospace Research "Elie Carafoli" and Romaero S.A.), the wing by the British consortium ASTRAL (Hamble Aerostructures and the University of Nottingham), the tail and empennage by the Spanish consortium between Airbus Helicopters España and Aernnova and the canopy and radome by the German FastCan consortium (KLK Motorsport GMBH and Gerg GmbH).

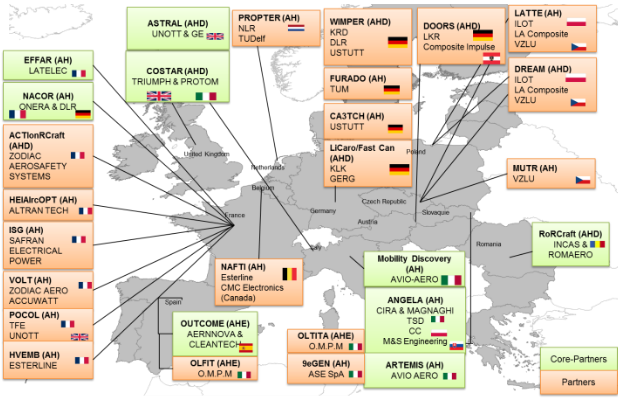


*Fig. 1: The RACER demonstrator partnership.*

### 1.2 The high-speed mission

The compound helicopter RACER (Rapid and Cost-Effective Rotorcraft) designed by AIRBUS-Helicopters represents an outstanding evolution of the successful X³-formula aiming its maturity for serial, commercial applications by ensuring optimal architecture, mission efficiency, comfort, noise and safety. The medium-weight compound helicopter is designed for cruise speeds of about 400 km/h and allows door-to-door transport, landings on unprepared external landing fields and conventional helidecks as well as rescue operations. The RACER particularly covers mission profiles in which higher flight speeds and agile vertical flight capability are

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crucial. The envisaged mission profile thus includes search and rescue services, ambulance services, coast guards, sea rescue, special operations and VIP transport. Increasing the cruise speed by 50% over conventional helicopters, the covered area is doubled within one hour of flight – the "golden hour" which is known to be decisive for a successful rescue operation. High-speed hence translates into a significant reduction in the search time, an increase in the number of rescued people, in the expansion of the search area or an increase in the number of flights. In turn, increasing the cruise speed means a significant reduction in the fleet or in the number of bases to cover the same rescue area within the same period of time [13]. Consequently, a high-speed helicopter enables a substantial improvement of both the search and rescue capacity and the overall economic efficiency of the operation.

### 1.3 The high-speed formula

The overall concept of the RACER (Fig. 2) implements the essential elements of the compound concept of the X³ demonstrator: main rotor, wing, lateral propeller and H-tail unit [13].

***Fig. 2:*** *The RACER*

The counter-torque compensating the main rotor torque is actively generated in hover by differential thrust of the lateral propellers, whereas with increasing forward flight it is passively generated by the vertical tails. In horizontal cruise, both lateral propellers generate forward thrust, while the wing and the main rotor each contribute around 50% of the lift. Similar to the conventional helicopter, the flight control in the vertical axis as well as around the longitudinal and transverse axis is carried out by the main rotor, while the control around the vertical axis is achieved by the differential action of the lateral propellers. The transition process from hover to forward flight is simple and uncritical, being conducted solely by the pitch reversal of the starboard lateral propeller. The relief of the main rotor in level flight through the lifting action of the wings is accompanied by a corresponding advantageous reduction of the need for torque compensation.

High-speed capabilities are achieved avoiding both, large advancing blade tip Mach numbers and – more especially – the retreating blade stall. This is achieved by slightly reducing the rotational speed of the engines and main rotor and reducing the blade pitch thanks to the lift and propulsion contributions of wings and lateral propellers.

In contrast to the X³ being characterized by a maximum re-use of available components, the architecture and construction of the RACER is developed from scratch to systematically and efficiently meet the mission requirements with increased weight and cost efficiency. The central element of this new arrangement is the novel "joined wing" designed by AIRBUS Helicopters [1][2][3], through which an optimal interdisciplinary synergy of structures, systems integration, aerodynamics and aeromechanics is achieved. This synergy is deemed the key for the required overall operational suitability of the compound formula.

### 1.4 The main vehicle`s architecture

Compared to the X³ demonstrator, the RACER has further significant differences in the overall conception, which denote strong evolution steps targeting high speed efficiencies, for example the slender fuselage, the completely retractable and faired landing gear, the faired main rotor head and the unique joined wings with pushers.

The helicopter's dynamic system consists of the main rotor, the main gear box, two engines and the two lateral pusher propellers with their lateral gearboxes and the drive shafts (Fig. 3). The main gearbox and both engines are positioned above the fuselage, with the engines behind the main gearbox. The main gear box directly drives the main rotor mast and the two lateral shafts, which drive the pusher propellers via a lateral gearbox. The supercritical shafts [4] are housed within the centre wing box of the upper wing and the lateral gear boxes are mounted within a nacelle at the wing tip providing an optimal aerodynamic wing-to-wing transition in terms of drag and noise.

The arrangement of the pusher propellers behind the joined wing gives the aircraft an inherent safety characteristic with regard to hoisting operations and emergency exits, in which the lower wing acts as a physical barrier to the lateral rotors [13]. Furthermore, the rotor disc of the lateral propellers is outside the cabin perimeter, the noise impact in the cabin hence being reduced and the risk of rotor burst impact within the cabin eliminated.

The innovative Safran-ANETO-1 engines implement a unique configuration, at which one engine can be kept running idle and automatically but quickly powered on for high power demanding flight cases. This operating mode allows for substantial fuel savings hence contributing to the reduction of the fuel consumption per NM by 15% at 180kts in comparison to conventional helicopters at 130kts.

The joined wing is composed of an upper and a lower wing showing a staggered arrangement with respect to each other within their connection to the fuselage, and an overlapped arrangement within the tip region. This root stagger is a result of the upper wing being aligned to the outputs of the main gear box to the lateral drive shafts and the lower wing incorporating the main landing gear integration and housing [13]. The rearward position of the lower wing proved to be simultaneously beneficial in terms of aeromechanics [12] and weight; it provides for a substantial increase of the pitch stability of the helicopter, hence simultaneously reducing the size and weight of the horizontal plane, and reduces its downwash interactions during low forward speeds. The pusher propellers contribute to that positive weathercock effect and, in addition, increase the dumping and directional stability of the helicopter. The small wing planform and the mutual outboard wing overlap allow considerably reducing the main rotor download and its negative impact on the helicopter`s performance in hover. The rotation of the pusher rotors is chosen taking advantage of the vortex generation within the nacelle [8], hence considerably reducing the power needed for high-speed flight [9]. The allocation of the rotors behind the trailing edge however sets some drawbacks in terms of acoustic emission which is a function of the rotor disc distance to the wings [10].

Due to its basic triangular truss characteristic, the joined wing stands out do to its inherent global stiffness, which is deemed one of the main drivers of the wing sizing [5]. The elimination of a continuation of the wing boxes within the fuselage enables a strong simplification of the upper deck architecture giving room for a simple and accessible accommodation of the main gear box and its suspension. The upper wing is hinged at two crossbeams connecting the left and right wing within the upper deck and the lower wing is hinged at two frame locations within the stub wing, the stub wing being a structural part of the airframe and simultaneously providing for the main attachment points of the landing gear leg and its housing in retracted position [13].

The integration of the landing gear within the lower wing allows keeping a simple, short and hence lighter main landing gear with a simple retraction kinematic. The lower wing`s internal volume is used as additional buoyancy volume to contribute to the prevention of capsizing in a water ditching scenario.

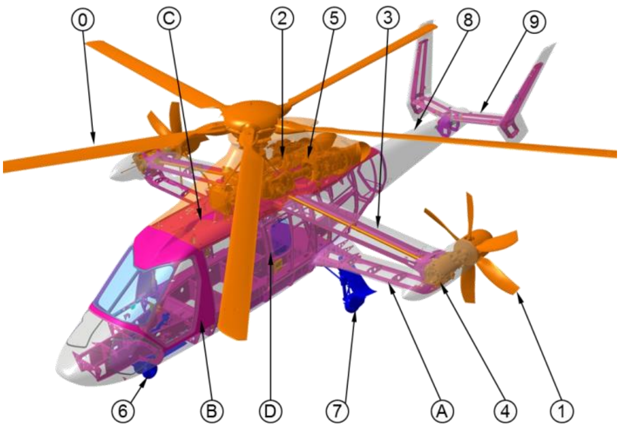


***Fig. 3:*** *The basic architecture of the RACER: Orange: dynamic system with main rotor (0), lateral pusher propellers (1), main gear box (2), lateral drive shaft (3), lateral gear box (4), engines (5). Pink: main inner framework structural members, subfloor (B), upper deck (C), frames (D), wing (A), tail boom (8) and empennage (9). Nose (6) and main landing gear (7).*

The H-shaped empennage shows less interaction with the wake flow of the rotor head and fuselage, whereas the double-kink of the vertical fins minimizes the interference drag with respect to the horizontal tail plane [6], [7].

The tail boom features an asymmetric cross section designed to exploit the main rotor down-wash targeting additional passive anti-torque capabilities in hover and an associated relief of the differential operation of the lateral propellers.

## 2. THE CENTER FUSELAGE

### 2.1 Architecture

The main structural components of the fuselage are the nose section (A) with the canopy (1), the centre section (B) – delimited between frame 2 (2) and 5 (5) – and the intermediate section (C) that extends from frame 5 (5) to frame 7 (7). Frame 7 corresponds to the detachable interface junction to the tail boom (Fig. 4). The cabin and cargo volumes are confined within the centre section B and the intermediate section C respectively.

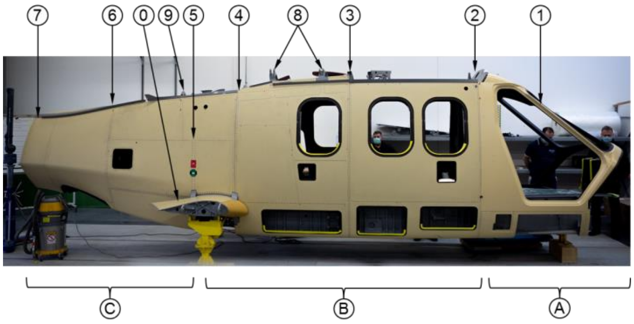


***Fig. 4:*** *RACER fuselage basic arrangement: Nose section (A) with canopy (1); center section (B) with frame 2 (2), main frames 3 and 4 (3)(4), frames 5 (5) and 6(6), upper wig main attachments (8), stub wing (0) with lower wing main attachments, engine beam and engine attachments (9); intermediate section (C) with tail interface frame 7 (7).*

The fuselage is mainly composed of the upper deck, the subfloor region and the side shells, the subfloor region being delimited by the floor level and the lower shell. The subfloor compartment includes the fuel tank and the landing gear compartments. A sliding door is arranged within the port side of the helicopter and one hinged cockpit door is arranged at each side of the canopy. One luggage door is arranged at the port side of the helicopter right ahead of frame 4. The lower shell shows a flat surface between the main subfloor longitudinal members in order to allow for a safe emergency landing in case of landing gear malfunction and to keep ground clearance limitations.

The core section of the centre fuselage is allocated aft of the sliding door between the main frame 3 and frame 5 and incorporates the mounting of the main systemic components of the vehicle: the main gear box suspension, the engines support, the wing interconnection and the main landing gear attachment.

The subfloor incorporates two main longitudinal members (longerons) spanning the nose and the centre section, and being mainly supported at both main frames 3 and 4. The longerons provide for the lateral confinement of the fuel bladders as well as for support for the floors, systems and harnesses allocated within the quarter shell perimeter of the subfloor. A series of trap doors allow the access to the systems housed within the quarter shell compartments. A rear trap door is installed within the intermediate section between frames 6 and 7 providing access to the removable interface frame 7 and the systems allocated in that perimeter.

The main landing gear wheels are housed within the subfloor perimeter of the fuselage requiring corresponding cut-outs within the lower shell. The structural continuity within this perimeter is mainly restored by a longitudinal keel beam which extends from the main frame 3 to the frame 6 which simultaneously delimits individual tank compartments.

The upper deck is essentially continuous all along the fuselage, hence providing an optimum in terms of global stiffness and strength (Fig. 8). The upper deck incorporates a set of longitudinal members providing support for heavy masses such as engines, main gear box and the main wing attachments, as well as for systems and harnesses allocated within the cabin and cargo compartment.

## 2.2 Design, new technologies and production

The fuselage design was developed entailing the best compromise in terms of production costs, structural weight, system integration, crashworthiness and, last but not least, the overall electrical network. This compromise has been especially tailored to the specific requirements of the vehicle as a demonstrator and its unique development context. As a result, the airframe is generally characterized by a hybrid design in terms of materials and construction. The fuselage upper, lower and side shells are fibre composite sandwich constructions. The side shells of the intermediate fuselage sections are manufactured by the German Fraunhofer Institute IGCV using robotic automate fibre placement technologies (Fig. 5).

***Fig. 5:*** *Robotic automated fiber placement of the starboard side shell (by courtesy of Fraunhofer IGCV); primed and trimmed side shell ready for installation.*

The production follows an innovative process chain [11] combining an over-core lay-up of the entire arrangement on a positive tool, swapping into a negative tool and curing. The process achieves an outstanding quality of the part and demonstrates the potential of a substantial reduction of the production costs in comparison to a traditional manual lay-up for serial applications.

The inner supporting framework of the fuselage – frames, longitudinal beams and crossbeams – is mainly metallic (Fig. 6). The frames, crossbeams and upper deck beams are integral, lightweight aluminium milled components which advantageously integrate primary and secondary interfaces to adjacent structural members and systems. As an example, the main frame 4 shows a large integrative function simultaneously incorporating main rear main gear box strut attachments as well as landing gear and lower wing attachments within the integrated stub wing spar. The frames are conveniently split into segments facing assembly and production costs requirements, the splices being essentially allocated at lowest loaded regions.

***Fig. 6:*** *Inner view of the fuselage assembly: subfloor structure, side shells and machined metallic framework members (by courtesy of the Romanian consortium RoRcraft).*

The subfloor longitudinal beams are designed as a stringer stiffened sheet metal construction with chemically milled sheet metal web and machined caps, seeking for an optimum weight and cost efficiency as well as crashworthiness (Fig. 7).

***Fig. 7:*** *Main landing gear section (stub wing and center fuselage) with frame 4 and 5, root and end ribs, stringer-stiffened longerons, sandwich center keel beam, machined structural floor (by courtesy of the Romanian consortium RoRcraft).*

The centre keel beam and several tank separation bulkheads are, in contrast, composite sandwich parts providing adequate both-sided fuel tank bladder support. The hybrid structural design is deemed advantageous in

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terms of electrical structural network – the individual metallic framework members and the systems being adequately interconnected to provide for an efficient electrical path and crashworthiness.

The floors are either milled aluminium or sandwich components (either metallic or carbon composite). In addition to some fibre composite components made of glass and ceramic fibres, carbon fibre reinforced components of various types of fibre and semi-finished products are mainly used. The metallic structural components are mainly made of aluminium and titanium; some fittings are made of high-strength steel to cope with high stress levels, fatigue or thermal requirements. The engine deck is essentially a traditional stringer stiffened titanium skin including some local thermal protective means ensuring fire-proof capabilities.

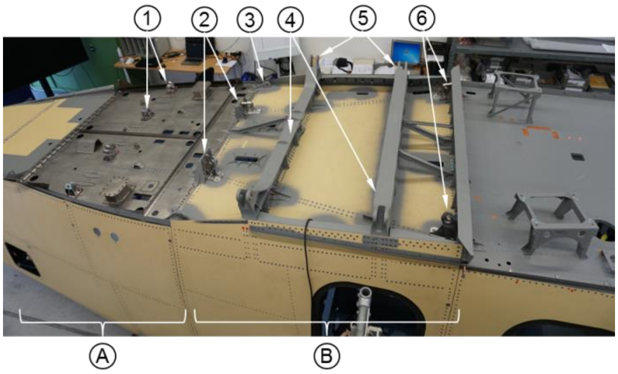


***Fig. 8:*** *View on upper deck with engine deck (A), mechanical deck (B) and front upper deck; cross beams (4), main gear box strut attachment points (2)(6), upper wing attachment points (5) and (3), engine fixations (1).*

The canopy represents a highly integral carbon structure with sandwich skins and closed profile post sections (Fig. 9). The radome is a hybrid structure with a glass fibre reinforced frontal area enabling radio-transparency and a surrounding carbon sandwich structure providing bird impact resistance. The canopy integrates bonded, lightweight, erosion-resistant and bird strike proof windshields.

***Fig. 9:*** *Canopy and nose structure with hybrid radome; installed canopy (courtesy KLK).*

## 2.3 Testing

### 2.3.1 General testing strategy

As the RACER in its current composition is devised as a flying demonstrator and in consequence a non-serial product, there is no need for a full certification but aiming for a permit to fly only. In consequence, the status as demonstrator offers certain simplifications in order to achieve the permit to fly mainly related to the testing activities.

The well-established procedure of following the building-block approach (Fig. 10) remains the essential basis for the RACER's testing strategy.

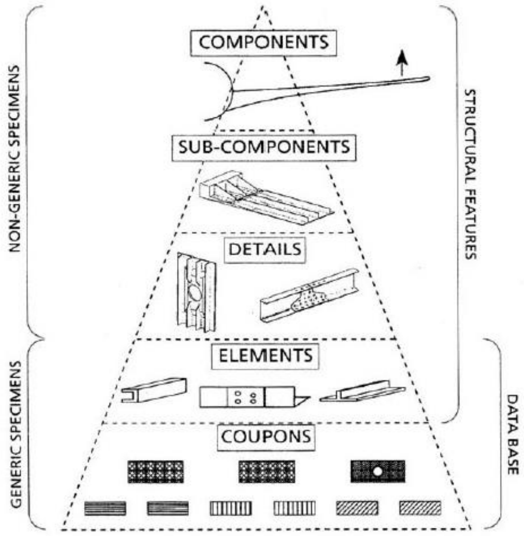


***Fig. 10:*** *General philosophy of the building-block approach [14]*

Focus of this paragraph in this paper is the uppermost level of testing as coupons, element, and up to sub-component; all testing is according to what is described in the standards and less unique compared to the upper level tests.

As described in the previous chapters the RACER's configuration does not only include new design features but the complete formula is new and not comparable to rotorcraft developed by AIRBUS in the past. Even its formal predecessor X³ consists of a fundamentally different wing concept and upper deck design. Consequently, one additional level on top of the testing pyramid of Fig. 10 needs to be considered.

Consequence is that, in addition to the uppermost level shown in Fig. 10 – the component level –, a complete generic test level needs to be added for proving that the representation of the vehicle in the numerical models (so called global Finite Element Model, GFEM) is accurate enough. This is proven on the flying demonstrator where, in the final assembly phase, unitary loads are applied on significant points which generate a predicted deformation at other spots. The measured displacements are then to be compared with the predicted magnitudes based upon the GFEM representation. This top-level test ("*GFEM correctness test*") will be performed at Airbus Helicopters in a late stage of assembly.

Second scope of this GFEM-correctness test is as well to "tune" the Finite-Element-representation of the helicopter in a manner that the differences between prediction and measured result are minimised. For this Young's moduli, thicknesses or the modelling strategy of junctions can be adapted in the model in order to achieve a higher fidelity in the predictions. With doing so the quality of the load extraction is improved as well hence lifting the theoretical substantiation on a higher level and providing a more precise prediction for the flight test campaign.

With showing that the representation of the RACER in the GFEM is sufficient in terms of correlation between measurement and analysis, it is demonstrated that the models can be taken for load extraction in regard to sizing of the components as for example fuselage, wings, and tail unit. But as these components again consist of new features, design principles, and materials, it has to be proven that all structural components can take their design load. As the Authorities and regulations require demonstration by analysis and test, the substantiation documents need to be proven by a limit load test at least, despite all analyses performed. In consequence, all partners contributing to the structural build-up of the RACER have to perform tests of their components. And, as the GFEM-correctness test described previously proves the validity of the interaction of all components, the components can be tested separately. A general zoning of areas of interest are the upper deck, the main landing gear section and the wings (Fig. 11).

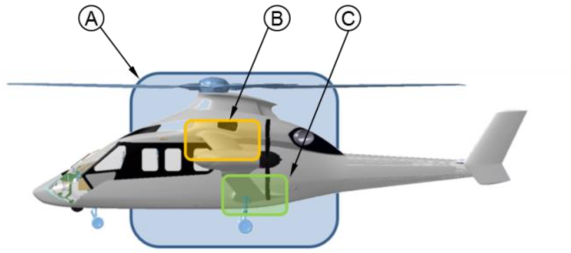


***Fig. 11:*** *Zoning of areas with completely new architecture: Wings A, Upper Deck B and main landing gear section C.*

An additional advantage of the strategy to perform limit load tests on separate full-scale component tests is that testing is possible even beyond limit loads without damaging the flying prototype and that observations from the flight test campaign can be studied on the individual items on ground. Higher costs are a disadvantage due to the need for additional production of large structural areas. On the other hand however, complex and costly test rigs would have been needed for a test campaign on the fully assembled prototype regarding the overall dimensions of the entire vehicle.

### 2.3.2 Main testing activities of the fuselage

The biggest difficulty in developing the testing strategy on the fuselage is the complexity of the loading in the fuselage in general. The wing configuration as shown in Fig. 3 features load introduction points at the fuselage in the mechanical deck region and in the lower canter fuselage subfloor-group where the stub-wing connects to the subfloor group. As the loads in the wings are significant and moreover magnitude and orientation change fundamentally during the different flight phases, the testing in the upper deck is complex. As can be seen in Fig. 3 the upper deck is a populated area with significant load introduction points from the main gear box, the anti-torque device, and the wings. They all interact and for example the principle of generating anti-torque is changing between hover and high-speed flight, the flow of forces in the mechanical deck changes completely. An extremely sophisticated mechanism of levers, actuators and semi-elastic boundary conditions would be the consequence.

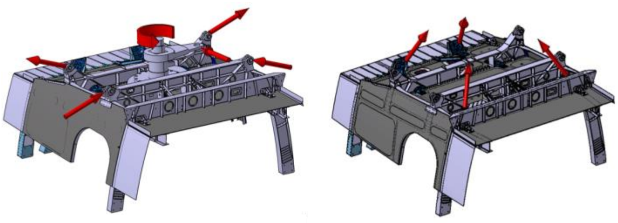

***Fig. 12:*** *Test specimen representing the main structural parts in the upper deck area B of figure 7, (by courtesy of Romanian Consortium RoRcraft).*

In order to simplify the test procedure, the strategy is to identify the highest loaded items per flight phase by analysis and then to predict their deformation and corresponding stresses for the most characteristic loading condition. Then in a separate Finite-Element model of the complete test set-up an arrangement of the individual actuators and suitable boundary conditions has to be defined in a manner that one identified part after the other is tested individually but in the context of the complete arrangement as the part is embedded in the full testing article. As shown in Fig. 12, for example in the left figure the lugs for the wing attachment can be tested or in the right area the load introduction points for the main gear box struts. Of course, the actuator directions, magnitudes, and boundary conditions (pinned, fixed, floating in one direction, etc.) have be adjusted so that the best analogy between real structure and its representation in the test set-up is achieved. The criterion for best analogy is the best fit of loading condition, displacement, and stress magnitude or distribution respectively at the critical spots. The individual boundary conditions are not shown in Fig. 12.

In this manner all new design principles can be tested within a representative structural environment and subsequently form a matrix where all important junctions are covered as well.

Main structural items in the mechanical deck are:

- the load introduction areas of the main gear box struts to the frames and the torque panel,
- the load introduction of the wing spars to the mechanical deck and their interconnection in the upper deck,
- the torque reaction area of the main gear box, and
- the area of the thrust introduction spots from wing to the fuselage.

Second region in the RACER's fuselage with completely new design principles is the main landing gear area C depicted in Fig. 11, which includes the attachment of the main landing gear and lower wing within the stub-wing. The corresponding test article is shown in Fig. 13. On top the principle to retract the main landing gear in lateral direction into the centre fuselage (similar to most larger civil aircraft) is new in the context of a winged helicopter. Of course, impacts on the energy absorbing behaviour in case of emergency landings are the consequence as well as an influence on the stiffness in the subfloor group as due to the retraction kinematic big openings in the lower shells of the fuselage and the stub wing are necessary. All of these aspects, design principles, and the examination of the global structural behaviour due to this design change is collected in a separate “stub-wing test”, as depicted in Fig. 13.

Main structural items in the stub-wing test are:

- the spars in the stub-wing,
- the load introduction pints of the lower wing,
- the load introduction points of the main landing gear including actuators, and
- the centre longeron forming the main load path in this region as single remaining major structural item.

***Fig. 13:*** *Test specimen representing the main structural parts in the stub wing area C of with partly removed shells, (by courtesy of Romanian consortium RoRcraft).*

Iin this stub-wing test the same procedure applies for identifying the sizing load cases, the corresponding arrangement of actuators, the definition of the individual load magnitudes, and the suitable boundary conditions. As well in Fig. 13 the boundary conditions are not shown for clarity as they can change load case by load case and by item to be tested.

The current status on the upper-deck test mid of 2021 is as follows: for the critical components all sizing load cases are defined, the appropriate boundary conditions are defined, the test rig is almost completely built and the test specimens are in manufacture. The stub-wing test will be performed after the upper deck test. The first tests are scheduled to start end of 2021.

## 3. THE WINGS

### 3.1 Architecture

The ASTRAL (Advanced wing Structure for Rotorcraft Additional Lift) design and build is conducted by Hamble Aerostructures Limited (HAL) in conjunction with the University of Nottingham Centre for Aerospace Manufacturing as part of the Clean Sky Airframe Integrated Technology Demonstrator (ITD) consortium. It consists of an upper and lower wing joined to the fuselage and to each other by a cradle which holds the gearbox, a movable trim flap on each wing, a nacelle protecting the gearbox and flight systems and three fairings at the main junctions (Fig. 14).

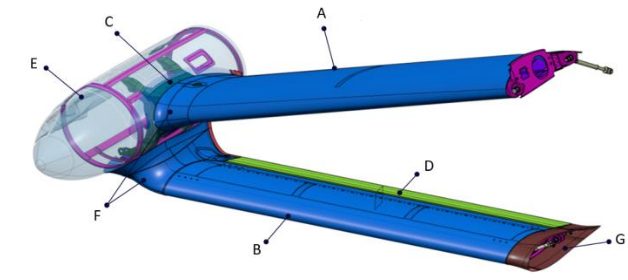


***Fig. 14:*** *ASTRAL wing basic arrangement: (A) upper wing, (B) lower wing, (C) cradle, (D) trim flap, (E) nacelle, (F) fairings and (G) sponson cover.*

The wings are of a similar construction of classical wing-box design consisting of upper and lower covers, forward and aft spars and a D-nose (Fig. 15). The honeycomb sandwich upper cover is integrated with the D-nose as a single piece composite construction with co-cured T-section upper spar booms. The spars are separate composite L-sections to control the vertical tolerances. The composite AFP honeycomb sandwich lower panels are removable.

The upper and lower wing to fuselage and the wing to wing (WtW) joints consist of a pair of lug and pins to react Y (spanwise) and Z (vertical) loading and a strut to react X (forward) loading resulting in a safe life design, single load path (SLP) philosophy. This arrangement limits the number of axis in which the joints can transfer moments to not over constrain the wing architecture.

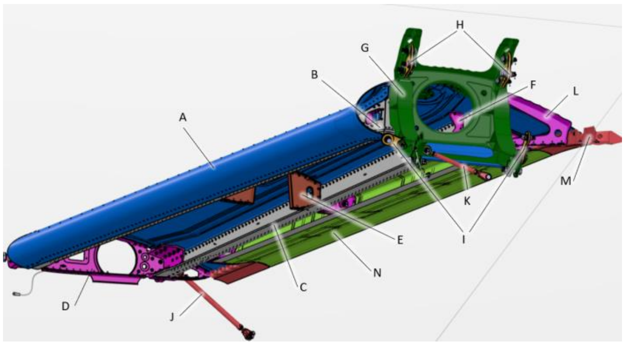


***Fig. 15:*** *Upper wing arrangement with lower panels, fairings and nacelle removed: (A) Upper cover, (B) Forward spar, (C) Aft spar, (D) Inboard rib and fittings, (E) Mid ribs, (F) Kink brackets, (G) Cradle, (H) Tri-plates, (I) Thrust and torque links, (J) Fuse Strut, (K) WtW strut, (L) OFW rib, (M) TEM and (N) Upper flap.*

The lateral drive line passing through the upper wing necessitates large openings in the inboard and mid ribs and the cradle. Two lower panels are connected with removable fasteners to permit access to the lateral drive line and the flap actuator. Kink brackets on the forward and aft spar provide support at the point the wing profile

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flairs out to accommodate space for a pair of couplings. Additively manufactured chop strand fibre composite trailing edge mouldings (TEM) join the upper and lower panels at the sections not occupied by the flap with the largest closed at the outboard end with an outer false work (OFW) rib.

The cast titanium cradle is connected to the upper wing box with multiple fasteners around the torsion box to limit rotation at the outboard end of the drive line to not exceed the rotational capability of the coupling. The cradle is attached to the lower wing by the wing to wing joint. The cradle holds the gearbox in four locations under statically determinate conditions in order to decouple the thermomechanical behaviour of gear box and wings: forward and aft tri-plates and a torque link reacting inertia and torque and an x-link reacting thrust all with spherical bearings to negate any force fighting with the gearbox.

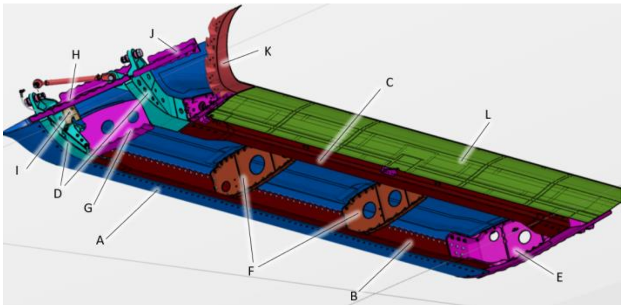


***Fig. 16:*** *Lower wing arrangement with lower panels and fairings removed: (A) Upper cover, (B) Forward Spar, (C) Aft Spar, (D) "Hockey sticks", (E) Inboard Rib, (F) Mid ribs, (G) Kink Rib, (H) Outboard rib, (I) Flexball bracket, (J) OFW rib, (K) TEM, (L) Lower flap.*

The lower wing inboard rib is a single piece machining incorporating the wing-box to fuselage connection with the inboard flap hinge and stub-wing cover connection. The WtW transition curves the lower wing up, which incorporates at that location an outboard end rib and a kink rib for load redistribution as well as a pair of machined curved end components called "hockey sticks" incorporating the main wing to wing attachment points and providing for the bending continuity within the lower wing. The forward "hockey stick" forms a stiff base for deflection requirements of the attached flex-ball bracket carrying the pitch control cable (Fig. 16). The lower panel is attached with removable fasteners to enable installation of the pitch control cable during aircraft assembly. Since the lower wing is pinned at both ends it is of secondary influence to the drive line clearance requirement.

## 3.2 Design and production

The most critical component of the ASTRAL build is the cradle, a single multi-function piece component holding the lateral gear box, as well as forming the wing to wing joint, constructed with cast Titanium (Fig. 17). The counter-gravity investment casting technology permitted the replacement of ~5 complex integrated machinings (wing-box end rib, all four cradle attachments and the WtW joint) into a single very near net shape component. Consequently generating significant improvements in the overall Buy-to-Fly ratio, weight and production productivity rate. Gearbox fatigue loading and deflection limits for the drive line governed the sizing of the cradle geometry.

***Fig. 17:*** *Cast titanium cradle trialed for machining capability*

Patterns are manufactured using SLA (stereo lithography apparatus) enabling complex features in addition to design changes during the manufacturing development phases. A centrifugal process is used to reduce inconsistencies in cooling rates leading to a homogenisation of grain structures. Two sets of development cradles were created to refine the flow analysis of the molten titanium. One used to ensure microstructural analysis, the other to develop machining capability.

Due to the complexity of the component only select interface regions of the cradle is machined with the remainder left as a cast surface. The combination of the SLA pattern production and a rotating waterfall shell application provides a surface condition of 6.3 Ra or less (close to machining) accommodated for within the fatigue analysis with a modest knock down factor.

***Fig. 18:*** *Structurally bonded upper spar boom T-return to upper cover at D-nose perimeter.*

The wing-box of the upper and lower wings are both an assembly of composite components; covers of a honeycomb sandwich and spars of a monolithic construction. The upper spar boom T-section is co-bonded to the integrated upper cover and D-nose with structural bonding to reduce the number of components and assembly time (Fig. 18).

The wing-box composites are sized by damage tolerance, defined by Barely Visible Impact Damage (BVID) under ultimate flight loading conditions. The upper wing, upper cover and spars are a combination of uni-directional (UD) and woven carbon plies. The UD-plies provide longitudinal stiffness to control the deflection of the wing as the height is defined by aerodynamics and are orientated in the spanwise direction. Woven plies are selected for the other orientations required for shear and balance due to their improved drapability over 90° angles (the T-return) and over core. The upper wing stacking design is a balance of structural efficiency and manufacturability.

The wing-box spars are assessed for secondary bending effects when subject to combined bending and compressive end-load. The lower wing is pinned at both the inboard and outboard ends; hence the effect of aero pressure is to bend the spars upwards. Thus, in conjunction with a simultaneously applied spanwise compressive end-load, the upward bending becomes enhanced.

The removable lower panels of the wings are constructed using Automatic Fibre Placement (AFP) technology which has been developed for over core to generate honeycomb sandwich structures (Fig. 19). AFP technology is a rate ready technology which increases consistency of the quality of the product. AFP is used instead of automated tape laying due to the reduced toe width enabling more complex shapes to be created, such as over honeycomb cores.

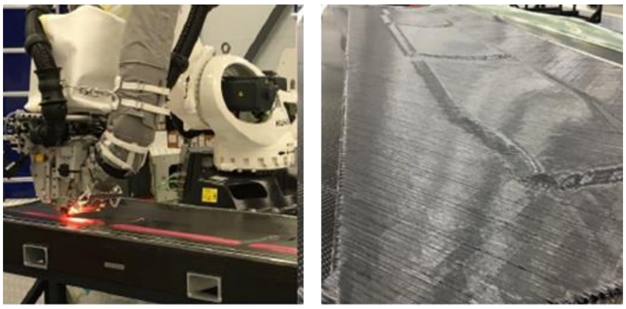

***Fig. 19:*** *AFP manufacture of honeycomb sandwich panels.*

The AFP process uses short width toes of UD-CFRP instead of the traditional hand laid woven CFRP for sandwich construction. This leads to geometric details which can affect structural capability of the panel such as gaps, overlaps, bird beaks, resin triangles and angular deviation. These geometric details can be considered in the following ways; trials, testing, design adjustment, AFP program adjustment and structural substantiation.

CATFiber assessments of the panel design produces the program to instruct the AFP machine. This provides the location, type and quantity of geometrical details listed above. Detrimental features were pushed to less critical locations (away from joints/core etc.) and tests were performed where this was not possible.

The inboard end of both wings is designed for forward crash conditions to prevent the wings articulating forward at risk to cabin occupant safety, with loading exceeding flight static and fatigue. The LSP architecture of the wing to fuselage joint leads all primary metallic structure to be sized with A-basis material properties with the steel pins classified as critical parts. The ribs, kink brackets and hockey sticks of the wing-box are standard machined aluminium.

The flap is a one-shot cure single piece composite construction (Fig. 20). A clamshell tool design forms the outer profile with flexible mandrels forming the inside profile. Plies are laid up into each half of the clamshell and around each mandrel. Full definition is required to be set into the mandrel such as ply drops, overlaps, debulking to ensure consolidation of the final component.

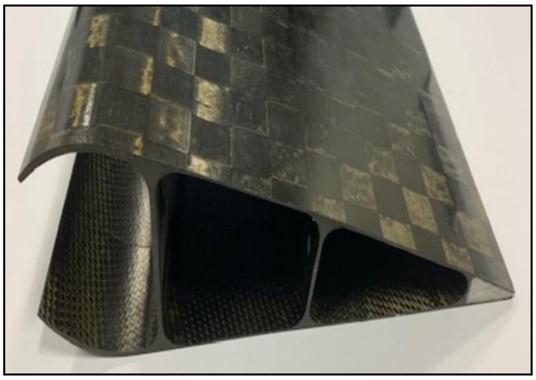

***Fig. 20:*** *Single piece composite flap*

Short trial sections of the flap have been manufactured using these tools to prove the process. The trials showed that twist, a known issue of composite manufacture, is negligible for this technique. Advantages are tool surface profile on all faces and reduced thickness tolerances.

The trailing edges of the wings which are not occupied by the flap require the upper and lower covers to be joined. These are complex geometries, especially outboard of the lower wing with double curvature, with relatively low loading requirements. The Trailing Edge Mountings (TEMs) are manufactured using additive layer manufacturing process using PEEK with short strand carbon fibre (AS4) material.

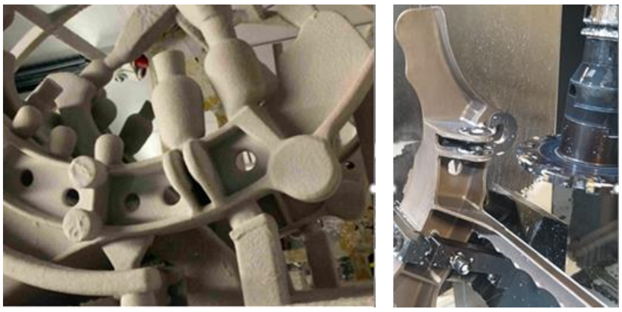

***Fig. 21:*** *Cradle manufacturing by CTI (Casting Technology Institute); de-shelled cast cradle prior to riser removal and chemical milling on the left; machining of the main attachment features on the right.*

HAL has deployed an end-to-end Model Based Engineering digital thread throughout the design, analysis, simulation, manufacturing, assembly and inspection phases. This Industry 4.0 approach has facilitated a series of stepped improvements in the product design and manufacturing including buy-to-fly ratio, part count, overall weight and production process sustainability. In turn, this has delivered significant reductions in overall development time and cost.

All composite components of the wing-box have been manufactured, machined and drilled, the metallics are machined. The cradle is cast (Fig. 21), machined with bushes installed at lug positions and undergoing final inspections. The build stage of the wings has been completed, they are assembled, fastened, with the next stage being the installation of the cradle.

***Fig. 22:*** *Build of the lower wing fully drilled and fastened ready for integration with upper wing and cradle.*

The next stage is the assembly of the cradle into the upper wing and the two wings together using fixures designed and manufactured by the University of Nottingham. This is to be followed by the build of the non-critical components of Nacelle, Flaps and Fairings.

### 3.3 Testing

The test pyramid of ASTRAL encompasses all levels, including coupon, element, detail, component and full scale as depicted in Fig. 10. For example, the structural bond of the upper spar booms to the upper cover means of compliance testing comprises two test set-ups, one for peel strength and the other for flexural strength, both of which concluded that the structural bond strength is comparable to the inter-laminar shear strength between any 2 plies of the composite stack.

The purpose of the full-scale wing test is to validate the static and fatigue strength of the primary load-paths, displacement of the upper wing and the wing FEM (Fig. 23). Due to the hinged attachment philosophy of the gearbox to cradle and the wings to the fuselage the loading philosophy for the test can be simplified to a single load application point at the gearbox and 3 discreet planes on each wing. The deflection of the wing is to be measured using sighting lasers and targets positioned within the upper wing.

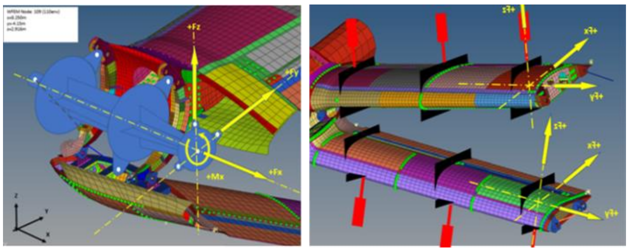

***Fig. 23:*** *Schematic of the full-scale wing test; gearbox and wing load inputs.*

## 4. THE TAIL AND EMPENNAGE

### 4.1 Architecture

The design and manufacturing activities have been performed by the Spanish companies led by Airbus Helicopters España and a consortium OUTCOME, composed by some Aernnova divisions and several Spanish research centres. The rear structure of the RACER is composed of the tail boom unit and the empennage and is mainly characterized – in contrast to conventional helicopters – by the absence of a traditional tail rotor (Fig. 24). As explained in prior chapters, the active aeromechanical duties of a conventional tail rotor are transferred to the lateral propellers.

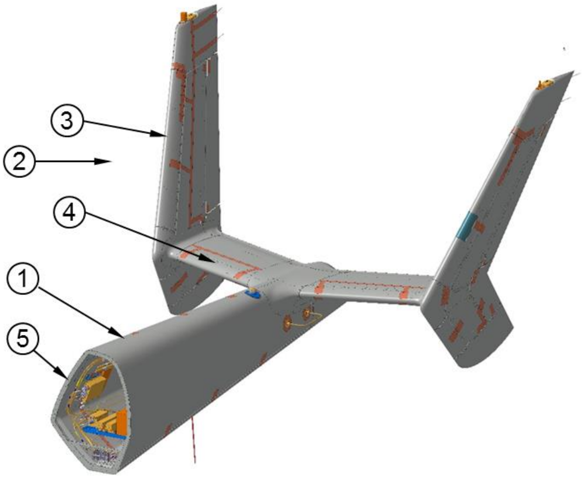


***Fig. 24:*** *RACER "rotorless" tail: tail boom (1) with fuselage interface (5), empennage (2) with horizontal tail plane (HTP) (4) and vertical tail planes (VTP) (3).*

The tail boom architecture is similar to conventional, modern helicopters, being composed of a monocoque tube and main frames providing for the interface to the airframe intermediate structure at its front end and the empennage support at its aft end.

The unique cross section of the tail boom is visible in Fig. 24, denoting a cambered shape especially designed to generate a transverse load as an effect of the main rotor downwash, hence passively inducing an anti-torque contribution [15][16]. This feature allows increasing the hover flight efficiency by about 10%, hence providing an outstanding contribution on targeting a maximization of the vehicle`s overall operational efficiency.

The tail boom loft, its tapering and slender transition to the empennage are optimized for drag reduction, but lead in turn to special challenges in terms of structural arrangement, and, more especially, in terms of the integration of the pivotable junction to the empennage due to space limitations.

The empennage architecture is unique for helicopters and features an H-configuration with a swept rearward horizontal tail plane (HTP) and two tip mounted double-tilted vertical fins (VTP) (Fig. 24). The double tilt of the VTP denotes the upper and the lower portion above and below the HTP resp. having different sweep and dihedral angles. This special arrangement emphasizes the strong tailoring for high-speed efficiencies, however at a certain expense of structural and technological complexity.

The upper portion of the VTP incorporates a rudder which can be actuated in flight for trim adjustments.

## 4.2 Design and production

The tail boom represents a monocoque, composite sandwich structure which is longitudinally split in two parts following the most optimal technological strategy whilst achieving minimum structural weight. A special design has been introduced targeting an optimization of the shell`s weight by maximization of the core coverage in combination with a specific sequential curing procedure. This strategy allows overcoming the typical limitations of honeycomb core drapability and enables core continuity even within sharp curvatures (Fig. 25).

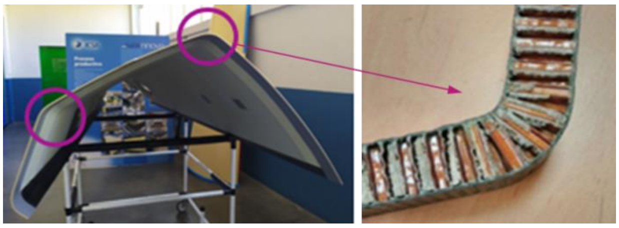

***Fig. 25:*** *Tail boom shell with continuous sandwich arrangement over sharp curvatures*

The tail boom incorporates three frames, one front metallic closing ring frame which provides for a flanged screwed connection to the intermediate fuselage, and two rear frames which integrally implement the attachment of the empennage to the tail boom (Fig. 26). The horizontal tail is essentially attached to the upper rear portion of the tail boom by two main lug joints – connecting the front spar of the horizontal tail plane to a hybrid rear intermediate frame – and a set of struts attached to the rear metallic closing frame of the boom. The interface of the empennage to the tail boom is pivotable in order to allow for an on-ground adjustment of its angle of attack in the range of ±5º and for a corresponding exploration of the most efficient setting during the flight test campaign. The design of the empennage attachment is especially challenging from a structure-mechanical perspective in terms of the small available design space (about one A4 sheet) and the corresponding large magnitude of the interface loads.

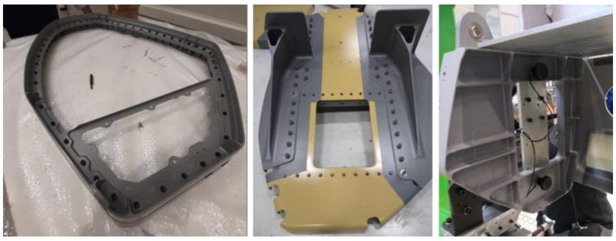

***Fig. 26:*** *Tail boom frames: interface frame to fuselage and both rear frames for the empennage support.*

The transition of the horizontal stabilizer to the tail boom is fully faired by means of a set of monolithic composite parts which ensure minimum interference drag whilst following the trim adjustability. The rearmost portion of the tube represents a removable cover providing access to the adjustment struts.

Some equipment supports allocated within the tail boom as well as some access trap covers have been designed and manufactured using either metallic (Scalmalloy) or thermoplastic (ULTEM9085) additive layer manufacturing technologies.

The horizontal tail plane is a composite sandwich shell construction with two spars, two root kink ribs and two end ribs at the outboard tips. The leading edges are composite monolithic parts which are stiffened by means of a set of composite nose ribs and are mainly designed for bird impact resistance. The basic structural arrangement of the vertical fins is similar to the horizontal plane, the spars being rigidly interconnected to the spars of the horizontal plane by means of an aluminium intermediate nodal bracket providing for stiff and strong bending load continuity to the horizontal plane. The fillets within the intersection of the fins and stabilizer are covered by separate monolithic fairings, and the fin tips are closed by composite covers.

The inner framework structure of the horizontal tail is manufactured as a single one-shot part using resin transfer moulding (RTM) technologies and incorporates the spars and both root and end ribs (Fig. 27). The production of this part is characterized by a high complexity in terms of tooling design, injection logic, pre-form layout and demoulding operations.

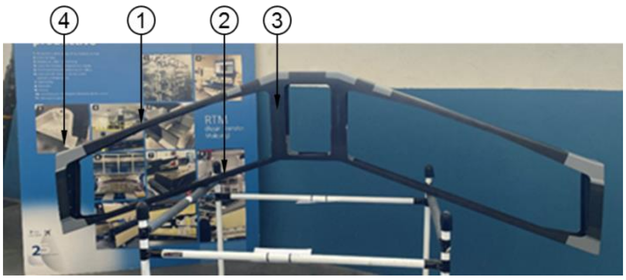


***Fig. 27:*** *The integral RTM part of the inner framework of the horizontal tail plane*

The trim rudders of the fins are designed and produced as highly integrated RTM parts with inner foam core, allowing the integration of five individual parts including the closing and load introduction ribs.

HS RTM Torsion box is currently the biggest RTM flying part developed at Airbus Helicopters and hence represents one of the technological cornerstones of this project.

Analogous to the tail boom, several secondary parts such as access trap covers or fairings have been produced using metallic or thermoplastic additive layer manufacturing techniques in ULTEM9085 (Fig. 28).

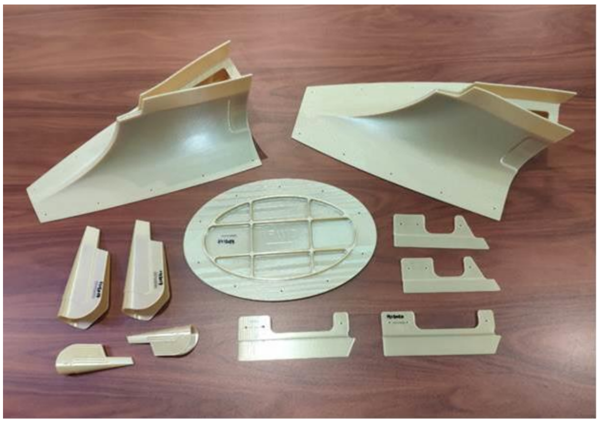

***Fig. 28:*** *Secondary tail parts manufactured by thermoplastic additive layer techniques.*

Titanium additive layer manufacturing techniques have been applied on the trim rudder hinge fittings (Powder Bed Fusion PBF/ Selective Laser Melting SLM), representing one of the first primary structural items produced for helicopter related part applications at Airbus. The fail-safe capability is achieved by applying traditional back-to-back features.

### 4.3 Testing

The on-ground test campaign of the tail and empennage basically refers to the testing pyramid as already presented in Fig. 10 and implements the following main topics:

- Dedicated coupon testing of new materials, such as for the additive layer manufacturing parts.
- Sub-component testing on critical items such as the connections of the horizontal tail to the tube as well as the interconnection between fins and horizontal tail with subsequent finite element correlation analysis.
- Determination of the limit and ultimate load strength capabilities on a specific full tail boom test specimen with mounted horizontal tail (without fins), the assembly being attached at the fuselage interface frame (Fig. 29). The load introduction is accomplished by equivalent load actuation within the horizontal tail structure.
- Overall modal testing and evaluation of the natural frequencies in comparison to the numerical predictions.
- On top the tail boom will be integrated in the GFEM correctness test as introduced in chapter 2.3.

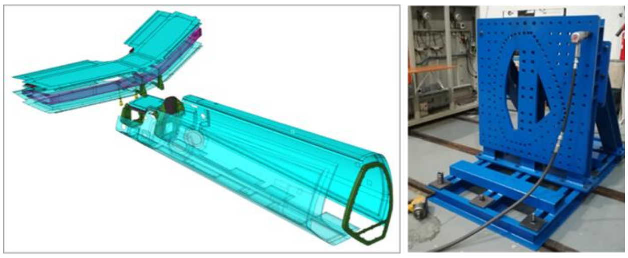

***Fig. 29:*** *Rootless full scale test specimen and main support jig for static testing.*

## 5. CONCLUSIONS & OUTLOOK

In brief the status on the work regarding primary structure of the RACER can be summarized as follows.

- The RACER’s conceptual design as described in former publications was translated into a real design. The chosen design principles turned out to have no relevant obstacle during its detailed elaboration and translation into a practicable structure regarding manufacturing, assembly and integration of systems.
- Status June 2021 the individual activities on the RACER’s main structural components reached a high level:
  - Almost all of the RACER’s structural components are manufactured.
  - The integration of all major components is almost completed. The assembly of the fuselage is almost completed and the integration of systems is starting. The wings and the tail parts are in final assembly.
  - The fuselage is equipped at that time at Airbus. The wings and the tail parts will be sent to the final assembly line at Airbus in the second half of 2021.
- All new technologies which were scope and part of the research work of Airbus and its partners were integrated in the RACER successfully or carried out during manufacturing respectively as planned. All intended technology bricks in the airframe and wing perimeter have been implemented without un-expected difficulties.
- The testing strategy is fully developed for the complete primary structure. At status mid of 2021 the tests on coupon level are completed as well as most tests on element, detail and sub-assembly level.
- The main structural tests are defined and build up at the partner’s testing laboratories or their chosen test laboratories respectively.
- The test specimens for the separate full-scale main structural tests are assembled or are currently in assembly. The first main structural component tests are supposed to start end of 2021.

The next steps in the airframe activities is to install major systems in the fuselage and then to transfer the fuselage to the final assembly line in the second half of 2021. In the final assembly line the remaining systems will be installed in the fuselage and then tail parts and wings are put together with the fuselage. Having this done the GFEM correctness test will be performed.

## 6. ACKNOWLEDGEMENTS

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