RUAG

Aerodynamics – Newsletter 19

Editorial

Dear reader,

In 2010 ICAO's (International Civil Aviation Organization) 190 member states agreed to a 2% annual fuel efficiency improvement up to the year 2050. One of the promising technologies to reduce fuel consumption and carbon emission is the "open fan" propulsor, also known as "Counter-Rotating Open Rotor" (CROR). Technological progress since the 1980s and environmental pressures have revived the interest in these propulsors consisting of two unducted co-axial counter rotating rotors. Engine manufacturers expect a fuel saving potential of up to 30% compared to today's level. Relying on RUAG's wind tunnel development and testing expertise with hydraulically driven model propellers and their associated instrumentation, Boeing and Rolls-Royce teamed up to define a generic open fan airframe configuration and build a sophisticated wind tunnel model of the airplane. The combined efforts have culminated in a comprehensive low-speed wind tunnel test campaign in RUAG Aviation's Large Wind Tunnel Emmen (LWTE), providing an extensive and currently unique data base for a complete CROR powered airplane.

The capability to develop specialized and technologically challenging test equipment in an extremely short time frame, as for this open fan test, is vital to the success of our customers and allows them to make the right decisions at the right time. RUAG Aerodynamics provides vital innovative services for development and research projects within the aerospace community.

Sincerely,

M. Guillaume

Michel Guillaume
Department Manager Aerodynamics

Open Fan

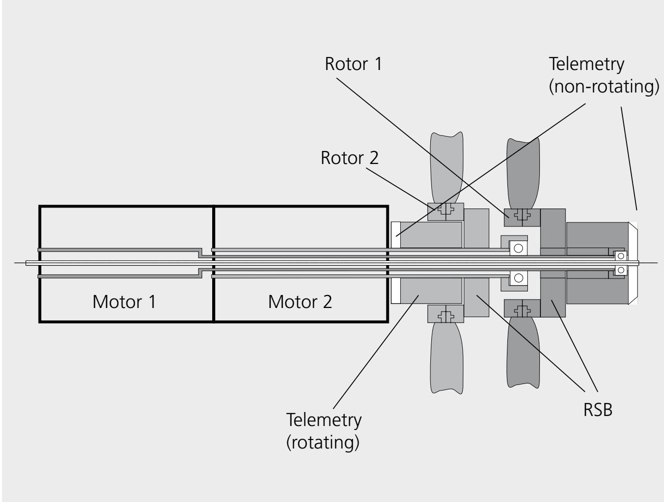
Since their commissioning more than 60 years ago, the wind tunnels of RUAG Aviation have been used to test aircraft models powered by propellers. This experience and the high level of competence when it comes to the development of custom wind tunnel testing solutions gave RUAG Aviation an edge when Boeing and Rolls-Royce sought an appropriate facility and propulsor technology for wind tunnel tests of their generic open fan airplane.

Unducted fan project 1988. Photo curtesy of Pima Air & Space Museum, Tucson, AZ

Concept

Traditionally, RUAG uses high power hydraulic motors to spin the propellers of its wind tunnel models. Although the power density may not reach the levels achievable with air turbines, the lower cost of these engines in both acquisition and operation make them a very attractive alternative while still providing abundant power. Customized solutions, taking into account model specific constraints can be developed within a reasonable budget. In this particular case, the counter-rotating configuration added a novel topological constraint to the propulsor design that vetoed the use of the RUAG "standard" motor types and called for a new development. The limited space within the nacelle also required the development of a new 6-component rotating shaft balance (RSB) tightly integrated with the miniaturized digital telemetry system. RSB, telemetry and hub are mounted as one single unit on each of the driving shafts minimizing the setup time in the wind tunnel and providing stable conditions especially for the load transfer between hub and RSB.

The loads on the complete airplane model are sensed by a fuselage internal 6-component balance that is encased by the high pressure balance crossing system. Clever design of this crossing system – so that only small and correctable interference effects remain – ensures accurate measurements while routing the high pressure hydraulic fluid to the propulsors.

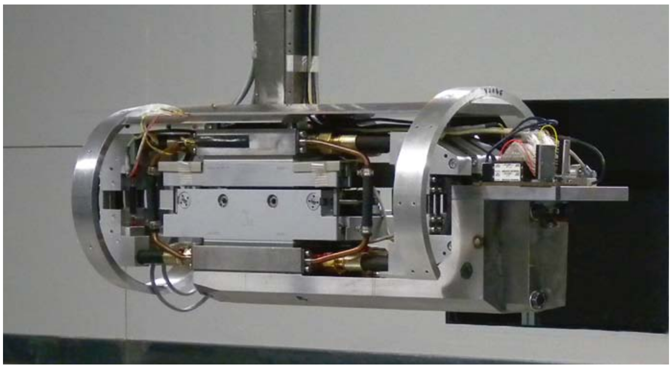


Concept drawing of hydraulic open fan propulsor simulator

Technical challenges

The hydraulic motors are obviously the central components of the propulsor. Two identical motors are mounted back to back driving each a single rotor. By way of a three shaft system the aft motor drives the front rotor and the front motor drives the aft rotor. The central fixed shaft carries the non-rotating part of the instrumentation in the spinner, namely the telemetry stator, accelerometers, and pressure taps. The design of the three shafts is critical with respect to stiffness and rotor dynamics. Even though the shafts are subject to significant lateral loads, they must remain relatively thin due to the geometric restrictions imposed by the nacelle lines. This raises the potential for resonances or even intrinsically insurmountable instabilities.

Hydraulic motors are a perfect choice for reliable, continuous and inexpensive high-power operation. The power of a single hydraulic engine simulator in our wind tunnel is typically similar to the power of a well motorized car. Due to the incompressible nature of the oil there is no expansion in the motor. Thus, contrary to air turbines where the expansion causes a sharp temperature drop, the oil temperature remains within reasonable levels, reducing the potential for thermal interferences on the main balance. Also, the cross section of the return lines can remain small with significant advantages when these have to be routed through thin airplane structures.


High pressure balance crossing system


RSB and telemetry mounted on motor

For efficient and precise wind tunnel measurements it is vital to set rotor speeds quickly and accurately to the desired levels and keep them constant independently of the varying aerodynamic loads during a run. The new control system and a 1 MW hydraulic power supply guarantee an accuracy of better than ±20 rpm over the full rpm range. A two-way coupling of rpm control with wind speed prevents critical flow situations which could overload the blades e.g. during an emergency shutdown of either the wind tunnel or the model propulsors.

The size of the RSB is governed by the predicted rotor load ranges and the desired accuracy levels. The resulting RSB dimensions together with the given nacelle dimensions, required the RSB to be attached to the side of the hub, which is a compromise with respect to the loading of the RSB. For rotor dynamic reasons a second design loop was necessary whereby the RSB mass was reduced and stiffness increased by a factor of two. At the same time provisions were implemented to significantly reduce the influence of the rotary speed on the measurements.

The transmission of the RSB and blade signals is always a challenge with powered wind tunnel models. Because of the counter-rotating topology and geometric limitations, slip rings, which were successfully used in past tests, could not easily be adapted to this specific application. Thus, a miniaturized telemetry system was designed and procured. 20 channels per rotor are available for RSB strains, temperatures, angular position and blade strains. 4.5 MBytes/sec of raw data is generated per rotor, calling for very quick storing and data processing capabilities. Also, data storage requirements are tremendous and can easily reach many tens of terabytes for a single test campaign.

Dual hydraulic engine propulsor

An isolated nacelle test with a fully operational propulsor in our Large Wind Tunnel Emmen (LWTE) was followed by a very extensive campaign with the complete model of a generic passenger aircraft. The successful test was remarkably efficient and was completed without any incident.

To make sure that our customers are able to use the same advanced RUAG propulsor technology for all of their development steps, the components are designed to be compatible with other facilities with only minimal modifications on their infrastructure.

Conclusions

Under enormous time pressure and relying on its decade long experience RUAG Aviation developed a complete open fan propulsor simulator consisting of hydraulic motors, rotating shaft balances, telemetry, rpm control system, main balance crossing system and data processing system.

Test crew. This photograph is reproduced with the permission of Rolls-Royce plc, copyright Rolls-Royce plc. 2010

The potential of our hydraulics technology to allow customized solutions at very competitive costs both in initial investment and during operation was highlighted. The successful completion of the project in a short timeframe and the satisfaction of the customer confirmed the adequacy of the chosen technology and was the reward for the hard work. We are convinced that the knowledge gained from the unprecedented aerodynamic data base acquired during this test will profoundly affect the architecture of future airplane generations.

Recent publications and articles:

Dr. Peter Aschwanden, Dr. Jürg Müller; Open Fan Technology; Aerospace Testing International, Showcase 2011

Dr. Peter Aschwanden, Daniel Steiling, Dr. Jürg Müller; Die Suche nach dem Flugzeugantrieb von morgen; Swiss Engineering, STZ Schweizerische Technische Zeitschrift, Nr. 12, Dezember 2010

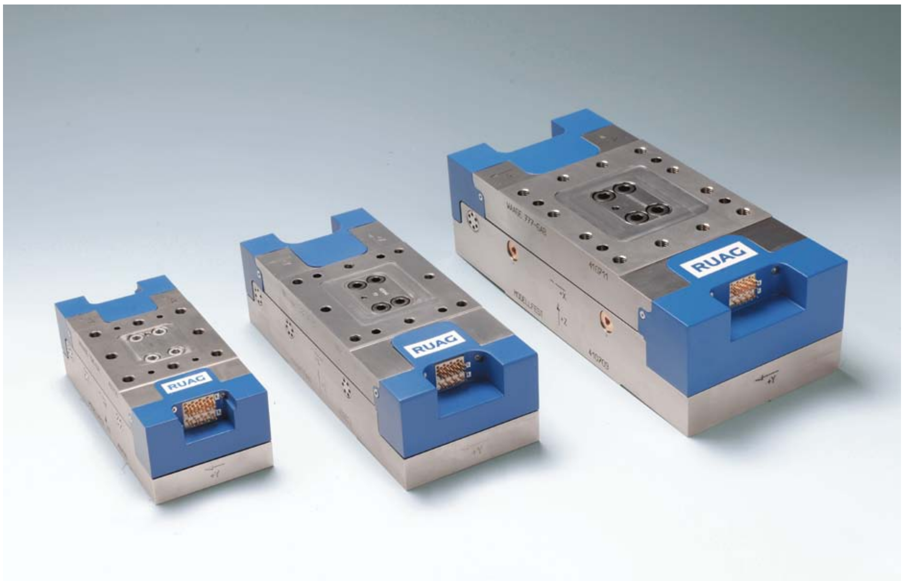
Kawakami, M., Sato, N., Aschwanden, P., Kato, Y., Nakagawa, M. and Ono, E., A Modeling of Unsteady Aerodynamic Forces Based on the Aerodynamic Analyses around a Simplified Car Model in Periodic Motions, Transactions of the Japan Society of Mechanical Engineers, Series C, Vol.76, No.768 (2010), pp.2006-2015.

Dr. Claus Zimmermann, Werner Häberli, Dr. Martin Monkewitz, Precise Measurement Technology Based on new Block-type and Rotating Shaft Balances, AIAA 2010-4541

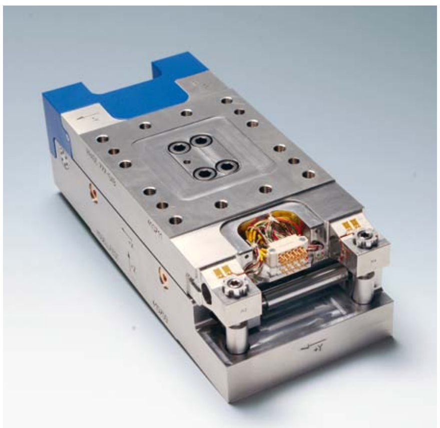
Dr. Michel Guillaume, Dr. Jan Vos, Alain Gehri, Philippe Stephani; Fluid Structure Interaction Simulation on the F/A-18 Vertical Tail, AIAA 2010-4613

New Block-type Balance 777

Small volume, large load capacity and stiffness as well as high accuracy characterize our 6-component strain gauge balances of the recently started block-type family "7xx". Requirements from a F1 racing team and from an Unmanned Air Vehicle (UAV) project motivated the development of a further balance of this family. Including this new balance "777", four balances of this family have been designed, fabricated, tested and are in operation with customers. They cover a wide load range (i.e. axial from 1'000 to 13'000 N and vertical from 3'500 to 30'000 N) while featuring exceptionally small dimensions and weights (0.85 to 7.5 liters and 5 to 50 kg respectively).



Family 7xx of 6-component balances; sizes 767 –777 – 788 – 796 are available



Our balance selection tool, based on an Excel spreadsheet, has been updated accordingly. With the entry of the expected maximum measurement loads, a selection of suitable balances is presented together with relevant information about geometry, weight and stiffness. Visit our homepage (www.aerodynamics.ch) to download the most recent version or contact us by mail. If you do not find the optimal balance for your specific application, please, send us your specifications, we might be interested to extend our balance family even further. Note that all RUAG balances are available for rent as well – an interesting and cost-efficient option for short projects within a tight timescale.

Recent Activities

Zerotracer

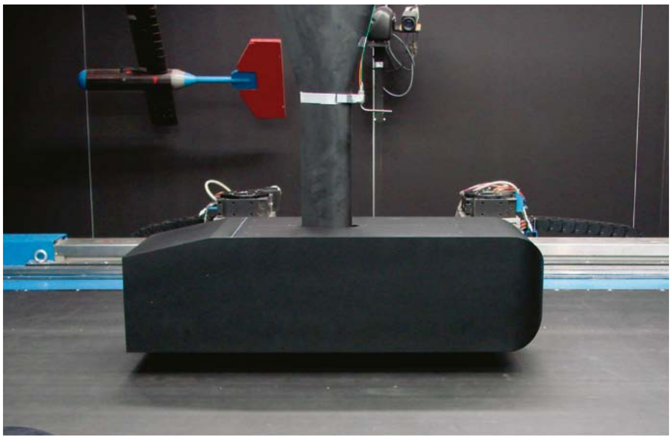
The electric motorcycle Zerotracer is an answer to our increased need for mobility paired with a requirement to reduce emissions. Its aerodynamic fairing, optimized in the wind tunnel, offers room for two persons, comfortably seated and protected from the weather. The electric motor and the clever design allow a top speed of 250 km/h and propel the vehicle in 4.5 seconds from 0 to 100 km/h. At a constant 80 km/h the motor consumes a mere 7 kWh and with a conservative driving style a range of up to 350 km may be achieved. Zerotracer is the first motorcycle to participate and finish the race, "around the world in 80 days" using alternative energy.

Air Conditionned LWTE Control Room

After another hot summer in 2010 with a lot of intense wind tunnel testing the control room of RUAG's large wind tunnel has been upgraded with a more powerful air conditioning system. Customers as well as the employees of RUAG are thankful for this relief from the almost unbearable heat on hot summer days; the control room temperature will now remain at comfortable levels allowing efficient and safe work.

Ahmed Body

Understanding flow conditions around representative and well-defined objects is of great value for scientific and educational purposes. In the commercial field such objects are used to calibrate and compare facilities. RUAG's composite model shop has designed and manufactured a modular and light-weight "Ahmed body", a well known, configurable shape from the literature. Its extremely stiff main body is equipped with a large number of pressure taps and is designed to house an internal balance attached to a protruding sting but can also be used in its original setup on posts. The Ahmed body, with its different configurations, will primarily be used in the fluid dynamics lab of the Federal Institute of Technology in Zürich but is also planned to be used for our internal research efforts in RUAG's Automotive Wind Tunnel (AWTE) e.g. to understand the aerodynamics of a ground-effect model that is quickly actuated lateral to the flow (Shaker project).



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