

The Recent Upgrade of the Model Scale Wind Tunnel of University of Stuttgart

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ABSTRACT

After being in operation since 1989, the 25% / 20% model scale wind tunnel of University of Stuttgart received its second major upgrade in 2016. In a first upgrade in 2001, a rolling road with a 5 belt system from MTS was installed. This system includes a steel center belt to simulate the road underneath the vehicle and four FKFS designed rubber belts for wheel rotation.

The recent upgrade now enables the wind tunnel to be used not only for standard, steady state aerodynamic measurements but also for measurements of unsteady aerodynamic effects. This enables the use of the FKFS swing system as a standard measurement technique. Therefore, the former balance was replaced by a balance manufactured by AND with a high Eigenfrequency and the ability to sample the measurement data at up to 1000 Hz.

The second large part of the upgrade was the replacement of the control system. With the new Wind Tunnel Control System (WCTS), control system. With the new Wind Tunnel Control System (WCTS) supplied by the German companies Werum and SEA, all wind tunnel systems are controlled and operated by a single system. This includes systems are controlled and operated by a single system. This includes the control of the new balance, the rolling road, the fan, the boundary layer control, as well as the traverse system and the pressure measurement system.

This paper will give an overview of the newly installed and upgraded systems in the model scale wind tunnel and includes also a summary of the characteristics of the tunnel.

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INTRODUCTION

Reduced scale model wind tunnels have being used since the early days of aerodynamics. Already in the 1930s, reduced scale model tests were done by IVK/FKFS on rolling roads (see [Figure 1](#)).

In comparison to full scale facilities, model scale wind tunnels offer faster turnaround times, as the surface on the vehicle that has to be modified is much smaller and lower costs – both for the wind tunnel as well as for the model build. Also, reduced scale models are typically available much earlier in the development process than the full scale ones.

Today the model scale wind tunnels are often used complementarily to CFD investigations. For small modifications on the model, the wind tunnel is much faster and cheaper than CFD, while CFD offers a much deeper insight into the flow field and is faster, when having large design modifications.



Figure 1. The first IVK/FKFS model scale wind tunnel in Stuttgart Untertürkheim with rolling road system in 1936

HISTORY

After IVK / FKFS relocated from Stuttgart Untertürkheim to Stuttgart Vaihingen, in the 1980s two aerodynamic wind tunnels were built in the Vaihingen Campus of University of Stuttgart for automotive research and development work: One full scale wind tunnel and one smaller model scale wind tunnel [1], both built as Göttingen-type wind tunnels with a $\frac{3}{4}$ open test section. Both tunnels are operated by FKFS. In Figure 2, the cross section of the model scale wind tunnel is plotted.

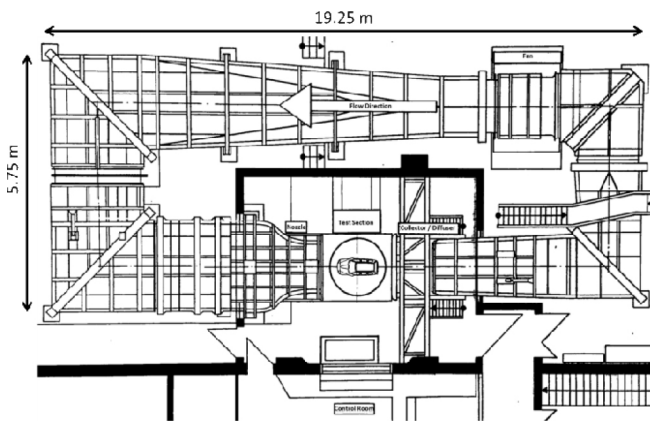


Figure 2. Cross section of the model scale wind tunnel, view from above

With a nozzle size of 1.6 m^2 and a fan power of 350 kW wind speeds in the test section of up to 80 m/s can be reached. The size of the tunnel is suitable for measuring models up to 30% scale, while typically scales of 20% and 25% are used.

The tunnel was originally equipped with a high precision 6 component underfloor balance manufactured by the German company Pfister, that was in use until the recent upgrade and was only replaced due to its inability to measure unsteady forces. This balance was sitting on hydrostatic bearings and the measurement range could be adapted by adding counter weights to the balance to account for different model weights. The only drawback was a small constant leakage of hydraulic oil into the balance room.



Figure 3. The test section of the model scale wind tunnel in 1988 with the traverse system in the background [2]

For temperature control, the airline is equipped with a heat exchanger, regulating the air temperature to a constant value of 23°C over the whole speed range. This guarantees the stability of clay models during testing.

There are two traverse systems installed in the wind tunnel: One three-axis traverse that is mainly used for the mounting of probes and moving them inside the test section and a four-axis model manipulator for automatic model installation. The later one is most useful, as the models are not modified inside the test section, but removed from it and brought to the model work shop next door. This helps to keep the test section and in particular the rolling road system clean from clay and allows also the work on more than one model at the same time. While one model is modified, the second one is tested and vice versa.

The model scale tunnel received a first major upgrade in 2001, when an MTS 5 belt rolling road system was installed, in parallel to the first rolling road upgrade of the full scale wind tunnel. Those two systems were the first 5 belt systems in automotive wind tunnels featuring a steel center belt (and four wheel rotation units with steel belts in the full scale wind tunnel). In the model scale wind tunnel, four FKFS designed rubber belts are used for wheel rotation, due to the small dimensions of these units. Figure 4 shows the test section after the first upgrade.



Figure 4. Test section of the model scale wind tunnel after the first upgrade

The control system of the wind tunnel was also upgraded and a system from MTS was implemented, controlling all the wind tunnel systems except for the two traverse systems and a common safety monitoring for all systems.

THE 2016 WIND TUNNEL UPGRADE

With the recent developments in the field of aerodynamics, the need for measuring not only steady state forces, but also being capable of measuring transient data emerged. Therefore, a new dynamic balance was bought from AND and was extensively tested in parallel to the former Pfister balance [4]. After being sure that the steady state results of both balances were comparable and the AND balance had at least the same accuracy as the Pfister balance, it was decided to completely switch to the new AND balance. This led to a wide range of tasks to be accomplished. The former control system was not able

to connect to the new balance and major changes would have been necessary to bring both systems together. But as the hardware of the control system was already around 15 years old, it was not certain how much longer this would be lasting.

The same issue was with the traversing system. The control hardware of the system was also around 15 years old and it already started to fault from time to time. Also, the connection between the traverse and the control system of the wind tunnel was only very limited, so measurements with a moving traverse system were always a bit difficult.

Therefore, it was decided to install a new common wind tunnel control system that would be able to control all of the wind tunnel subsystems, including fan, rolling road, balance, traverse system and others. The German company Werum was chosen as supplier, as they already had plenty of experience from equipping several wind tunnel facilities with their control system. Also they were able to guarantee the installation of the upgrade in a very limited time frame.

The MTS rolling road system remained the same, but the motors and the motor controls of the belts were replaced with ones built by the German company SEW, that are located less than an hour drive away. This guarantees fast response times in case of an error and a good supply with spare parts.

In the following sections, the main parts of the upgrade are described in detail.

Dynamic Underfloor Balance

The Pfister balance that was installed when the wind tunnel was built had to be replaced to allow the measurements of unsteady aerodynamic forces. It was replaced by a balance manufactured by the Japanese company AND (see Figure 5), capable of measuring forces with a frequency of up to 1000 Hz.



Figure 5. Dynamic underfloor wind tunnel balance designed and manufactured by AND [3]

In contrast to the former balance, the dynamic AND balance does not use any hydraulics or hydrostatic bearings, resulting in a much cleaner balance room. The balance is also much smaller and is connected only by four cables to the measurement amplifiers. This leaves much more space under the test section floor and allows the

turntable to rotate in a larger field of $\pm 90^\circ$. The rotation then still is only limited by the supply cables for the rolling road system. In fixed floor configuration rotation of $\pm 360^\circ$ is possible.

Table 1. Capacity and accuracy of the AND balance [3]

Component	Nominal capacity	Measurement Range	Accuracy	Resolution
Fx (drag)	± 2400 N	± 500 N	± 0.1 N	0.015 N
Fy (side)	± 2400 N	± 500 N	± 0.1 N	0.015 N
Fz (lift)	-8000 N	$+250$ N to -2500 N	± 0.3 N	0.05 N
Mx (roll)	± 600 Nm	± 300 Nm	± 0.5 Nm	0.01 Nm
My (pitch)	± 600 Nm	± 300 Nm	± 0.5 Nm	0.01 Nm
Mz (yaw)	± 1200 Nm	± 300 Nm	± 0.5 Nm	0.01 Nm

The capacity of the balance is large enough so that no counter weights are necessary. This reduces the margin of error, as the wind tunnel operator no longer needs to make sure, that the balance is in its measurement range while measuring standard models. The Eigenfrequency of the balance itself is at 40 Hz. When a vehicle is installed on the balance, the Eigenfrequency of the whole system is reduced, depending on the stiffness of the model and the set up. Still, it is typically > 20 Hz, which is enough to cover the transient aerodynamic effects.

With the new system, there are two ways of processing the measured forces and moments. First, they are transferred via UDP-connection from the balance to the wind tunnel control system (WTCS) with a frequency of 100 Hz. WTCS uses this data to record the results for steady state measurements and measurements, with low frequency requirements. In these cases, the balance only works as a sensor, delivering the forces and moments to the WTCS for further processing.

When higher frequencies are required, the forces and moments are recorded directly in the AND system. Here the full resolution of up to 1 kHz is available. In this case, the wind tunnel parameters such as belt speeds, yaw angle, etc. are transferred via UDP from WTCS to the AND system, so that all wind tunnel parameters are known and can be saved together with the results on the AND side.

The model is connected to the balance over four rocker panel struts that are located between the front and rear wheels and through the wheel rotation units. The rocker panel struts keep the model in place while the wheels are rotating. They are also used to adjust the ride height of the vehicle and can be moved vertically in a range of 50 mm. With the wheel rotation units mounted on the balance, the rolling resistance and ventilation resistance of the wheels is an internal force and is not measured by the balance. The center belt is mounted on the test section floor, so that it has no influence on the balance and therefore on the measured forces and moments.

The AND system also controls the 6 airfoils of the FKFS *swing* system, so that the whole dynamic measurement process is handled by this system. The airfoils can be moved with very simple signals like for example sine waves, but also complex signals like a specific noise, measured when driving a vehicle on the road.

Wind Tunnel Control System (WTCS)

For the control of the wind tunnel, a system from the German company Werum was chosen. Their Wind Tunnel Control System (WTCS) is already being used in many automotive wind tunnels, mainly in Germany. In some of these wind tunnels the WTCS-system was installed when the tunnel was built, in others it was only installed in a later upgrade. With all this experience, especially in upgrading existing tunnels, Werum was a good choice when it came to upgrading the FKFS model scale wind tunnel, especially as the timeframe for the upgrade was quite short.

An important point for the upgrade was having a common system to control every system related to the wind tunnel and to have one single point of contact in case of an error. This not only simplifies trouble shooting for the user, but also gives great advantages by using the systems together in combination. One example is a truly parallel force and pressure measurement on a model, which is especially important, when it comes to transient measurements. Here WTCS system offers many possibilities.

WTCS is a modular LabVIEW-based software package for controlling and managing all parts of the wind tunnel including all subsystems, the test preparation and test result processing. It is based on scalable client/server architecture and consists mainly of 4 layers, as plotted in Figure 6. The lowest level consists of all the subsystems of the wind tunnel. They are connected to a data server, which is then connected to a management level and finally the user dialogues.

For controlling the subsystems, such as for example the main fan or the traverse system, Werum has a long lasting cooperation with the company S.E.A. Datentechnik, who is doing the hardware implementation and driver programming.

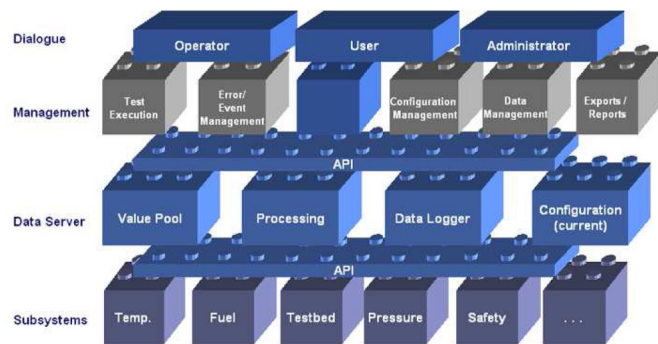


Figure 6. Basic architecture of the WCTS system [4]

In the case of the model scale wind tunnel, the hardware is split into 8 subsystems: Main fan, rolling road, turntable, boundary layer control, rocker panel struts, auxiliary systems, traverse system and model crane. The first 6 are connected to a NI CompactRIO embedded controller and the traverse and model crane to a second one. The controllers are then connected to the WTCS system.

Besides the subsystems, also the measurement systems are connected to WTCS. In case of the model scale wind tunnel these are the main AND balance and a PSI initium pressure measuring system, with up to 256 available channels. All the systems can be controlled and can measure simultaneously and all the results are marked with their

individual time stamps, which is especially important for unsteady measurements, where it has to be certain that the measurements are precisely synchronized.

The data server layer of the wind tunnel consists of two redundant servers: one windows server for subsystem control and one Linux server for data handling. In case of a hardware failure, the appropriate backup server can take control in a very short time, preventing the system from long lasting breakdowns.

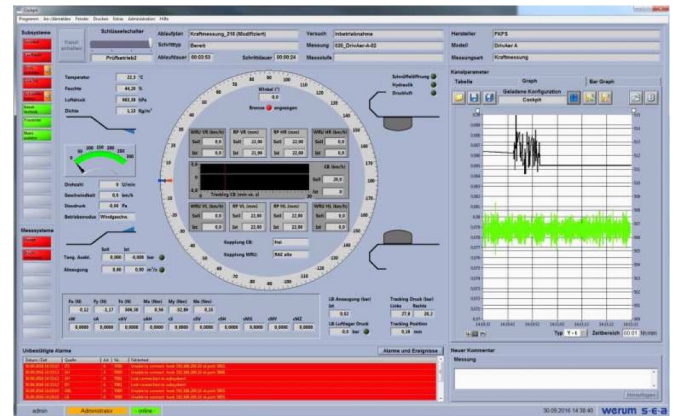


Figure 7. WTCS cockpit, giving an overview of all wind tunnel systems

The wind tunnel operator interacts with the system through a standard Windows PC. The WTCS operator panel consists of several windows that can be arranged within the WTCS application. On the main screen, the so called cockpit is displayed, giving information about all important aspects concerning the wind tunnel status in a clearly represented way (refer to Figure 7). On the right side, important values can be displayed in a graph or in a table and configuration descriptions can be added to the current measurement. This can both be done by the operator as well as by the aerodynamicist, as the cockpit is also run on the aerodynamicist's PC. Other than adding comments, only the operator can control the system and for the aerodynamicist all panels are for display purposes only.

Another important part of the WTCS system is the test sequence control. Here the measurements are set up and started. The operator can choose which subsystems will be used for the measurement and which test sequence to run (for example standard force measurements, yaw-sweeps or Reynolds runs...). The test sequencer then interacts with all the subsystems, transmits their target values and waits for the subsystems to reach steady conditions, before starting the measurement.

After finishing the measurement, a test report is automatically created, fitting each different type of measurement. For all measurement points a one page overview of the results, containing all wind tunnel settings, measurement description, the measured forces and the calculated aerodynamic coefficients is created as a pdf-file. For measurements with more than one measurement point, an additional overview report is created, again as a pdf-file, containing diagrams, showing for example drag over yaw angle. In addition to that, all values are stored electronically in tables for easy post processing.