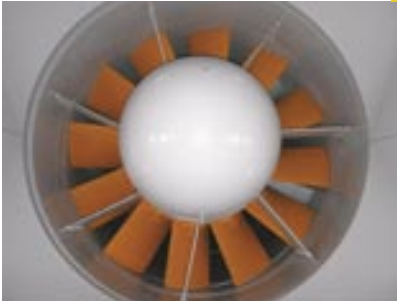


The Modine-Europe Climatic Wind Tunnel

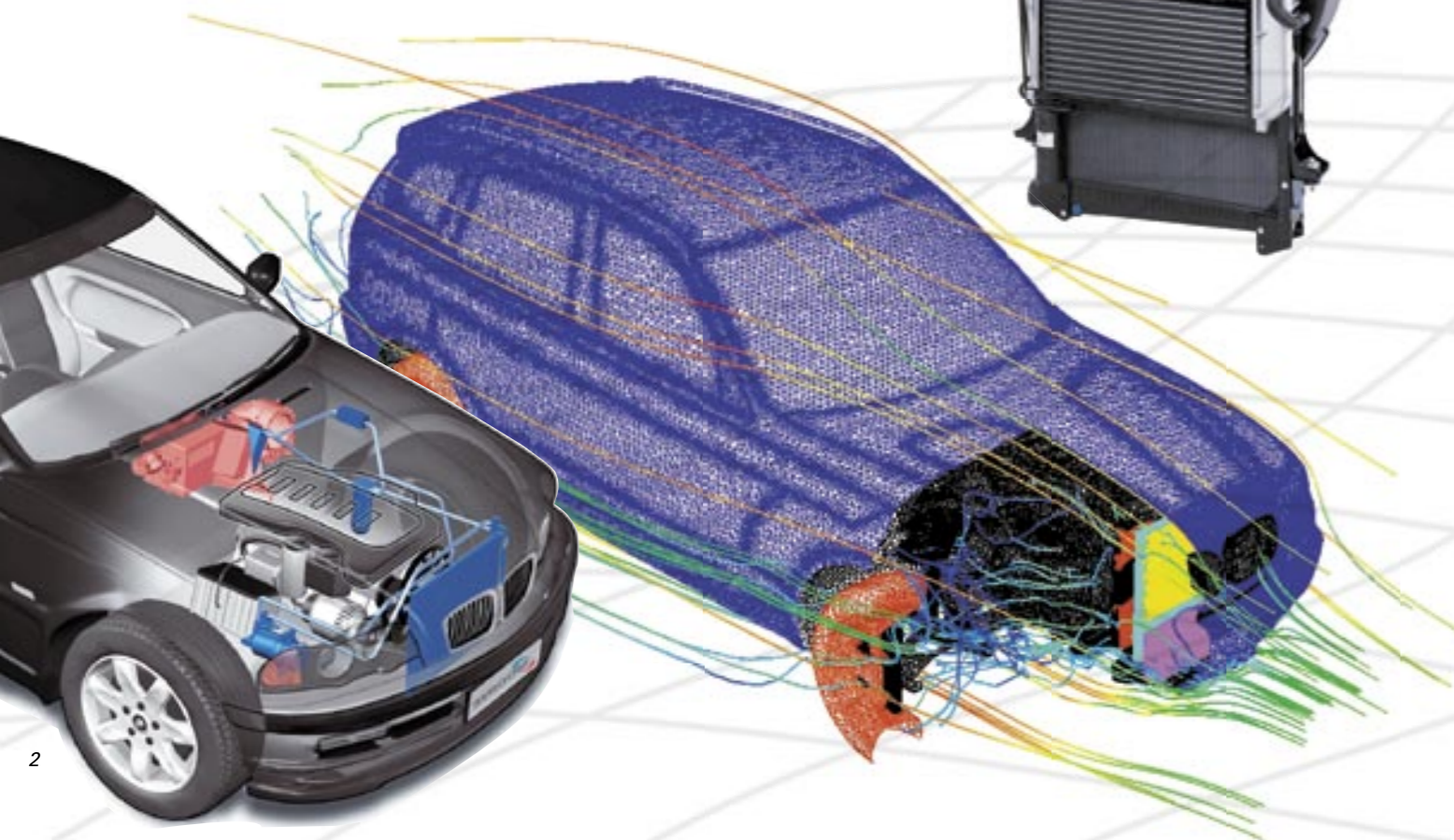


The Highest Degree in Thermal Management

From Components to Systems

The thermal systems of a vehicle are essential for reliability, performance, safety and comfort. They also influence the fuel consumption and exhaust emissions. The cooling of electronics is also critical. Moreover, the systems interact with each other. Therefore the thermo-management of the engine, transmission, exhaust system and vehicle interior must be considered together. Nowadays, individual components are increasingly assembled by the supplier into modules and systems. Modine was early in recognizing this development and actively promoted it.

However, as the model variations increase, the systems become ever more numerous and complex. At the same time, the new model development cycles become ever shorter. Only those who master computer simulation can keep pace. Nevertheless, experimental verification and fine adjustment of the systems, both in the laboratory and on the road, remain essential.



To meet the needs of its customers, Modine has included in the European TechCenter a world-class climatic wind tunnel; Fig.1 gives an impression of its size. It draws on the experience and knowledge gained from Modine's first climatic wind tunnel build in 1941. This wind tunnel, shown in Fig. 2, is still in use today. In all, Modine has five wind tunnels at four technical centers at strategic locations in Europe, Asia and the U.S.



Fig.1: The new Modine Europe climatic wind tunnel in Filderstadt-Bonlanden.

Modine's new climatic wind tunnel in Filderstadt-Bonlanden, Germany, serves mainly the development and testing of its own products. However, it is also available to external customers.

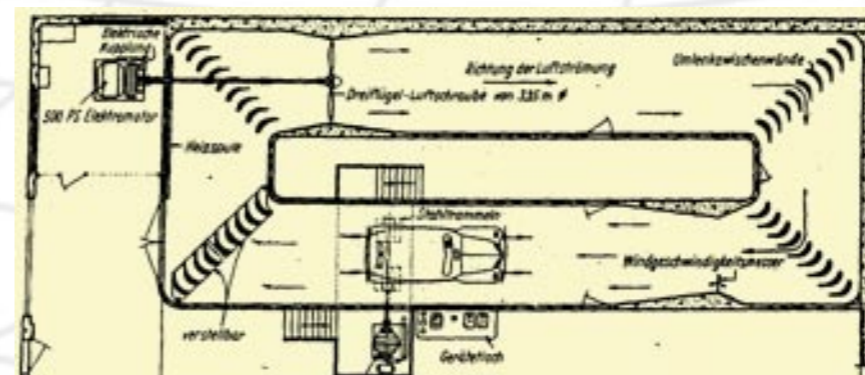


Fig.2: The first Modine climatic wind tunnel in Racine, Wisconsin, USA, built in 1941; Ref. ATZ 1943.

Requirements for Simulating Driving on the Road

With a vehicle wind tunnel, driving on the road is simulated, rather than reproduced perfectly in every respect. As with every simulation, the intention is to reproduce that which is essential for the process. Moreover, the cost must be no greater than absolutely necessary.

In a climatic wind tunnel, the first requirement is to simulate the climate, as defined by air temperature, humidity and solar radiation parameters. In addition, the flow field around the vehicle must be simulated, because it is critical for many thermal systems: it strongly influences the airflows through the engine compartment and the vehicle interior and past all the heat sources exposed to the external airflow. It also affects convective heat transfer at the surfaces of the vehicle.

It is not always necessary to reproduce all the parameters that characterize driving on the road. When testing the cooling of the major components, one can usually forego the simulation of sunlight. And, when testing and formally demonstrating de-icing of the windscreen after a cold start, no external airflow is required, as the official test procedure specifies that the vehicle is stationary.



The Concept

By analyzing the parameter requirements of the various vehicle thermal tests, they can be divided into two groups:

- Wind speed, temperature and humidity must be reproduced - with sunlight only for certain tests - e.g. climate control.
- Temperature, humidity and sunlight are reproduced – with the wind speed being only sufficient to keep the major components cooled.

Following this philosophy, Modine planned the climate-center - shown in Fig. 3 - with two facilities:

- a climatic wind tunnel (in the center of the picture), capable of temperatures above freezing. However, it is constructed so that the climatic envelope can later be extended, with temperatures down to -20°C , and with solar radiation.
- a climate chamber with a cooling fan (on the far right of the picture), in which the temperature, humidity and solar radiation are reproduced.

A compact installation.

To reduce the site area required, the wind tunnel is arranged with the return duct positioned above the test section and the auxiliary plant on several levels. Thus everything - including the workshops, office and meeting rooms - is accommodated in one building complex¹. An admittance control system is provided so that the two test facilities can be used simultaneously - with absolute confidentiality and secrecy - by different customers.

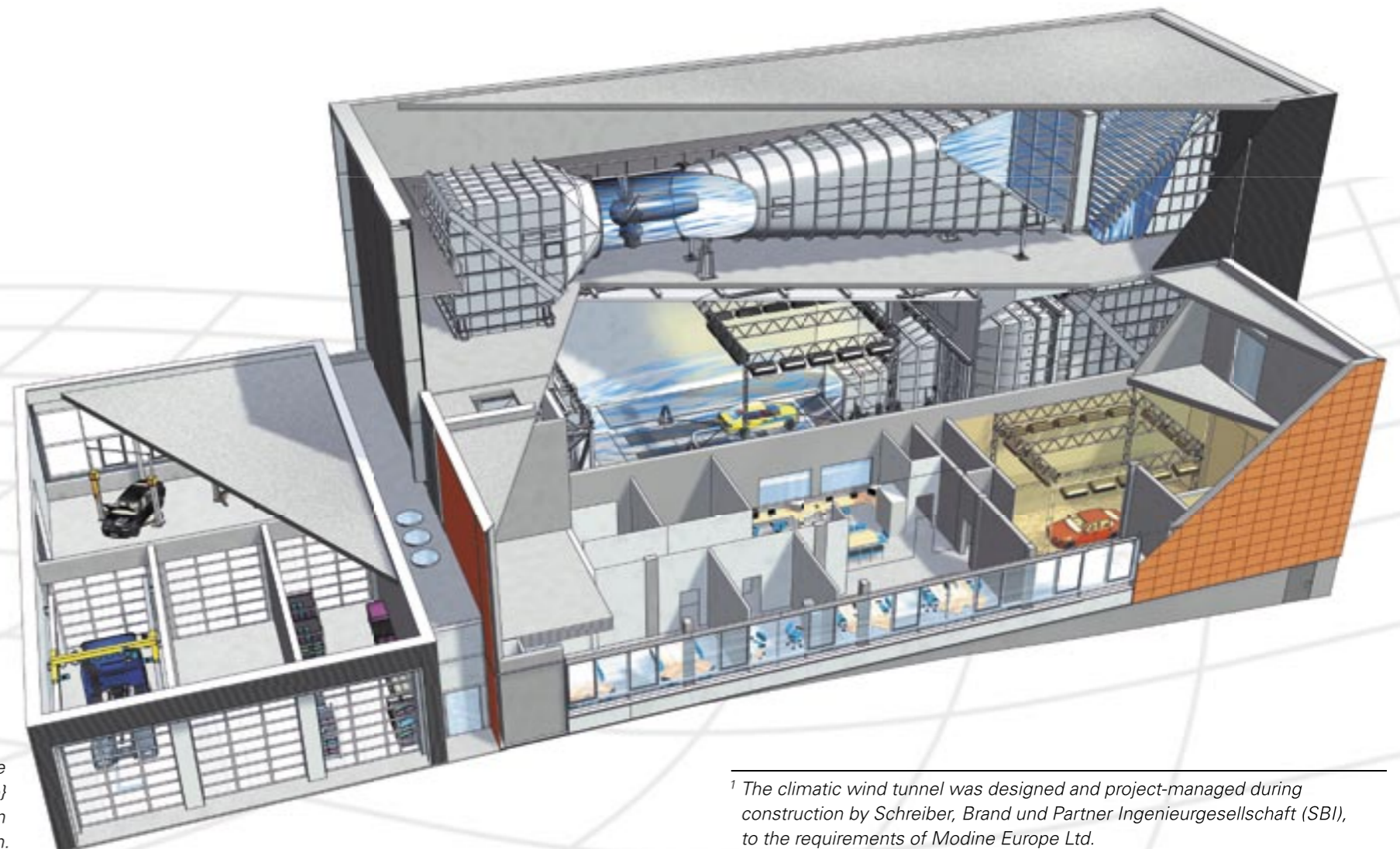


Fig. 3: The Modine (Europe) climatic center in Filderstadt-Bonlanden.

¹ The climatic wind tunnel was designed and project-managed during construction by Schreiber, Brand und Partner Ingenieurgesellschaft (SBI), to the requirements of Modine Europe Ltd.

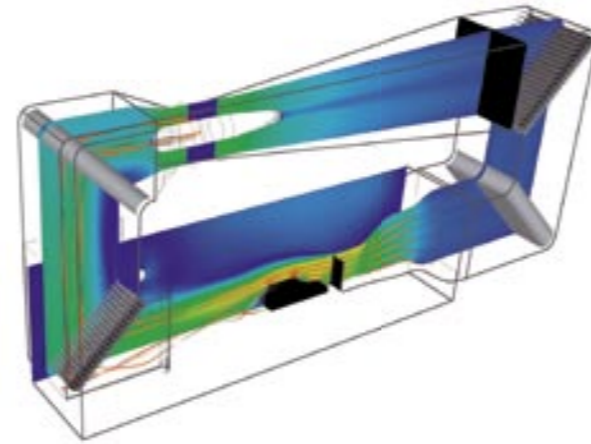
The Climatic Wind Tunnel

The Air Circuit

For the air circuit of a climatic wind tunnel, only a closed-return (Göttingen-type) is feasible. Therefore, as shown in Fig. 4, the new Modine climatic wind tunnel is of this type. The principal dimensions and performance data are summarized in Table 1.

Table 1: Climatic wind tunnel, dimensions and performance data

Nozzle area Passenger car / Truck	5.3 / 12m ²
Length of the test section Passenger car / Truck / Bus	14.3 / 15.8 / 19.3m
Wind speed Passenger car / Truck	250 / 130km/h
Drive power of the fan	1300kW
Temperature range	20 to 55°C
Cooling power of the wind tunnel	2000kW
Relative humidity	10 to 90%



The fan, with a diameter of 3.55 m and a maximum power of 1300 kW, propels the air via the long diffuser towards the heat exchanger. There it is brought to the desired temperature. To ensure that this is evenly distributed over the cross-section, its face area is ample at 36 m².

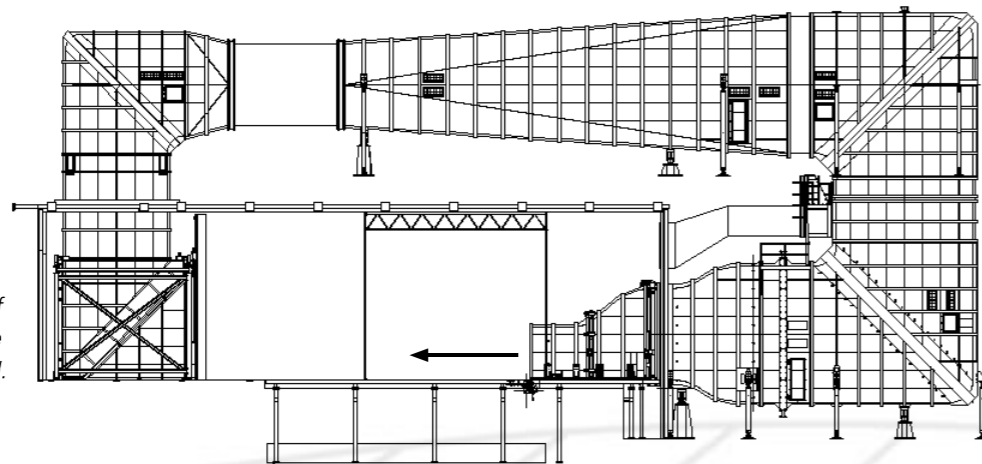


Fig. 4: The air circuit of the Modine {Europe} climatic wind tunnel.

The tempered air flows via two corners, each equipped with guide vanes, into the settling chamber - also with a cross-section of 36 m². From there it is accelerated progressively in the nozzle, up to a maximum wind speed of 250 km/h. On entering the working section, it flows over the test vehicle and is withdrawn via the collector.

The collector has a wide rectangular cross-section of 20 m² in order to ensure a stable airflow and to keep the static pressure along the test section constant. Via two more corners, also equipped with guide vanes, the air reaches the fan - which completes the circuit. The guide vane array of the lower corner (following the test section) is divided into two equal halves. By moving aside, they give test vehicles access to the test section.

The nozzle exit can be closed with a two-part flap within seconds. At the same time a bypass opens, leading the air above the nozzle and into the plenum. Hence whenever the test vehicle is required to be 'stationary' (i.e. in still air), the wind tunnel airflow bypasses the test section. Thus operation with rapid transients can be simulated, such as 'idle-stop' or 'stop-and-go'.

Two components of this circuit are critical for the utility and operating cost of the wind tunnel: the nozzle and the test section.

The Nozzle

The nozzle exit area, along with the specified maximum wind-speed - here 250 km/h, defines:

- the dimensions of the whole wind tunnel and thus much of the capital cost;
- the power of the fan drive and of the cooling plant - and with it most of the operating costs.

Consequently the nozzle exit area should be large enough to create a flow field over the test vehicle that is as realistic as necessary, but no larger. The relation between the frontal area of the test vehicle, A_{vehicle} , to the exit area of the nozzle, A_{nozzle} , is known as the 'blockage ratio' $j = A_{\text{vehicle}} / A_{\text{nozzle}}$. Many comparative measurements have shown that a climatic wind tunnel can have a blockage ratio much larger than that of an aerodynamic wind tunnel. For climatic wind tunnels, values of 0.3 to 0.4 have proven sufficient.

In such cases the flow field over the front part of test vehicles and the airflow in the vehicle interiors agree sufficiently well with those measured on the road, or in a big wind tunnel. For the Modine wind tunnel, the nozzle exit area, A_{nozzle} , was fixed at 5.3 m². For a passenger car with a frontal area, A_{vehicle} , of 2.0 m² this gives a blockage ratio of $j = 0.38$, which is just within the range given above.

For big trucks and buses, a nozzle exit area of 5.3 m² is of course much too small; for such vehicles a nozzle exit area of 12 m² is provided. To enable these two very different nozzle areas to be provided in one wind tunnel, the Modine climatic wind tunnel has a 'tandem nozzle'. As shown in Fig. 5, this consists of two nozzles arranged one after the other.

When a passenger car is in the test section, both nozzles are used in series. With a nozzle exit area of 5.3 m², a maximum wind speed of 250 km/h can be reached. If a truck or bus is being tested, the second nozzle is removed sideways from the wind tunnel, and the airflow is guided laterally by two inward-folding flat walls. With just the first nozzle, with its exit area of 12 m², a wind-speed of 130 km/h can be reached. This is quite enough for testing trucks and buses.

The big advantage of the tandem-nozzle is that the wind tunnel flow field matches the different vehicles in both height and width. The change-over takes less than 30 minutes.

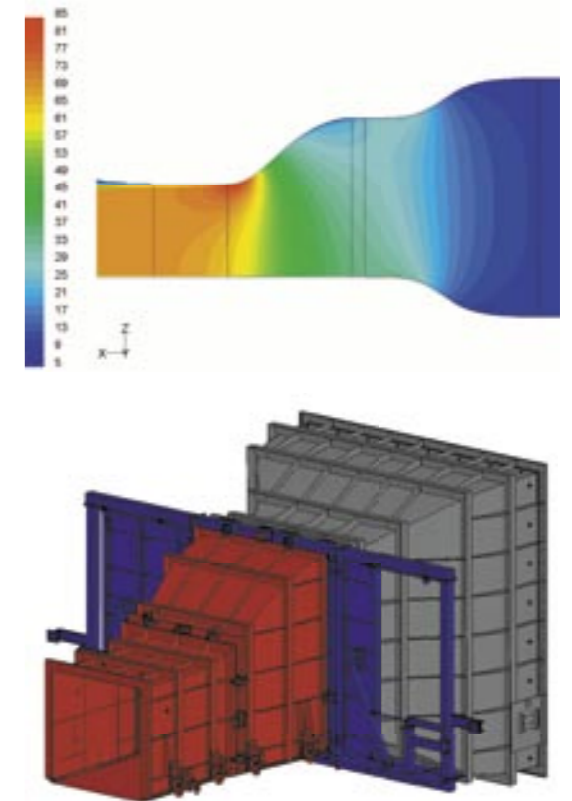


Fig. 5: The tandem-nozzle of the climatic wind tunnel; top: the velocity contours at the mid-plane, bottom: the structure.



Fig. 6: A passenger car in the test section with the small nozzle.

The Test Section

The test section of the Modine climatic wind tunnel is open, surrounded by a large volume chamber, the plenum. That is, the airflow at the top and side boundaries is free, rather than being constrained by walls. Consequently the test section is easily accessible and the test vehicle visible from all sides. In dimensioning the plenum, sufficient space was left to allow the later installation of lamps for the simulation of sunlight. The necessary carrying frame has already been installed.

A typical test arrangement for a passenger car is shown in Fig. 6. The rollers of the dynamometers can be moved longitudinally. Therefore the distance between the nozzle exit and the test vehicle can be varied, as well as front-, rear- and all-wheel drive accommodated. The extraction of exhaust gas is arranged so that the flow past the vehicle is not disturbed.

A big truck in the test section is shown in Fig. 7. Also in this case, the distance between the nozzle exit and the test vehicle can be varied, and different wheelbases accommodated.

When the wind tunnel is used with the 12 m² nozzle - as with commercial vehicles - the resulting test section is especially long, at 19.3 m. This makes it possible to test even long buses in the Modine climatic wind tunnel. It has proved advantageous to guide the flow over the bus by a "mantel", as shown in Fig. 8. The well-ordered wool tufts show that the flow along the sides and the roof is smooth, even at the rear.



Fig. 7: A big truck in the test section, looking towards the collector.



Fig. 8: A coach in the test section; the "mantel" improves the flow field around the sides and roof.

The Roller Dynamometers

The test section is equipped with two roller dynamometers, (Fig. 9) each with roller diameters of 2 m. Both can be moved longitudinally - even with the test vehicle - under push-button control, and the wheelbase set to between 2.3 and 6.9 m. The traction force and brake power ranges suit passenger cars and commercial vehicles respectively. The performance data are summarized in Table 2. Each dynamometer is equipped with two separate force measuring units for different working ranges. The maximum peripheral speed of the rollers matches the maximum wind speed of 250 km/h.

Table 2: Climatic wind tunnel: Performance data of the two roller dynamometers

Dynamo-meter	Brake (absorbtion) power	Circumferential speed	Traction force
Front	300kW from 83km/h	250km/h	13kN
Rear	450kW from 62km/h	250km/h	26kN

As well as steady-state operating points, with constant values for tractive force or speed, dynamic cycles can be driven, and coast-down tests can be performed.

To hold passenger cars on the rollers with the minimum impairment of the vehicle flow field, a special rotating hub-adaptor was developed for the restraint²; it is shown in Figs. 10 and 11. The test vehicles are fueled from their own tank. A 'driving robot' is available, Fig. 12; it is suitable for use with manual, as well as automatic transmissions.

Conditioning the Air

The air in the wind tunnel is conditioned, with a fresh air flow of 10000 m³/h blown in during testing; to ensure thorough mixing, this is introduced in front of the fan. An equal volume-flow of air is sucked out beneath the floor along with the vehicle exhaust and discharged via a stack. The supplied air can be cooled or heated to the desired wind tunnel temperature. It can also be used to pre-condition the wind tunnel before testing - for example during the night (in recirculating air operation).

To control the humidity, the fresh air supply plant includes an absorption-dryer and an array of steam injectors. The saturated steam is produced by a gas-fired boiler. The dew point can be set at between -15°C and 43°C; the minimum relative humidity is 10% and the maximum 90%.

The advantage of such a high, constant and conditioned fresh air flow is the excellent stability of the wind tunnel temperature and humidity over time, thus avoiding the wide excursions experienced at wind tunnels without such conditioning plant.



Fig. 9: The two-axle dynamometer.



Fig. 10: Mountings for holding a passenger car on the dynamometer rollers.



Fig. 11: Close-up of the rotating hub-adaptor.



Fig. 12: The driving robot.

² The development was carried out by AVL, Graz.

Calibration of the Nozzles

With the completion of the wind tunnel, the velocity-distribution $u(y,z)$ over the nozzle exit area was measured point by point with a pitot-static (Prandtl) tube; meanwhile the test section was empty. For example, that of the small nozzle is shown in Fig. 13. Both nozzles have very uniform velocity-distributions. The measurement of the velocity-distribution also provided the calibration of both nozzles.

In the Modine climatic wind tunnel, the control variable for the wind speed was chosen as the pressure-difference Δp_p between the settling chamber and the plenum. The static pressure in the settling chamber, p_v , is sensed via a ring-manifold and that in the plenum, p_p , with a 'pressure-can', that protects the sensing head from secondary-flows. Since the plenum is connected directly with the surroundings, the prevailing pressure there is equal to that of the outside atmosphere, p_∞ . Hence the wind speed is controlled by the 'plenum-method' - i.e. depending on the value of $\Delta p_p = p_v - p_p = p_v - p_\infty$.

The dynamic pressure q in the test section is obtained by multiplying the pressure-difference $p_v - p_\infty$ by the nozzle-factor f . The nozzle-factor accounts for the speed in the settling chamber being not quite zero and also that small pressure losses occur in the nozzle. Fig. 14 shows the nozzle-factor f versus the measured pressure-difference $p_v - p_\infty$ for the small nozzle. In the range of wind speeds used during vehicle testing, the nozzle-factors of both nozzles are virtually constant.

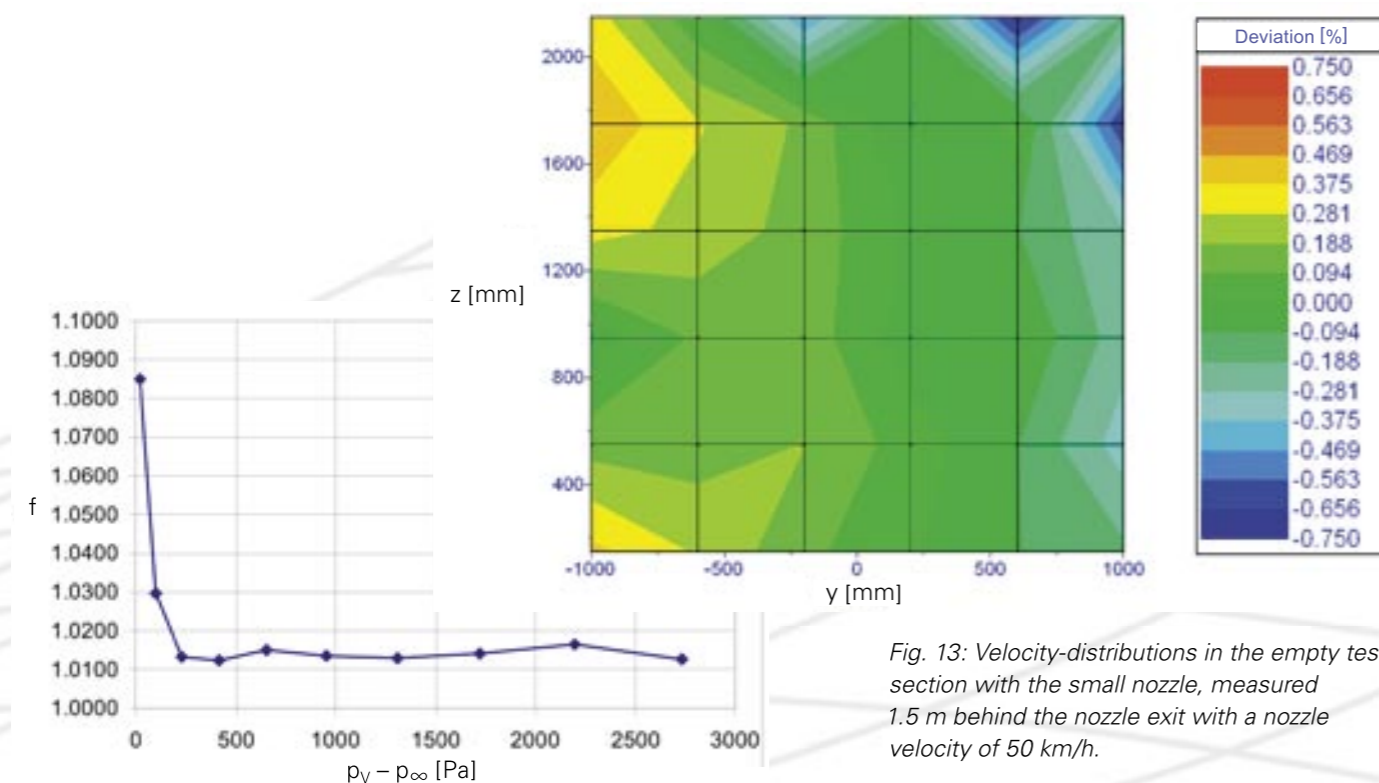


Fig. 13: Velocity-distributions in the empty test section with the small nozzle, measured 1.5 m behind the nozzle exit with a nozzle velocity of 50 km/h.

Fig. 14: The nozzle-factor f as function of the pressure-difference $p_v - p_\infty$ passenger car nozzle.

Setting the Wind Speed

When there is a vehicle in the test section, setting the wind speed needs to take account of three phenomena:

1. First the measurement described above is influenced by the presence of the vehicle near to the nozzle; it changes the nozzle-factor f . Hence this depends upon the distance between the nozzle and the test vehicle.
2. When flowing in a free jet with limited cross-section, the streamlines can pass further away from the vehicle than in the open air on the road. This causes the effective wind speed to be less than that intended; the larger the vehicle frontal area and hence the blockage ratio, the greater is this discrepancy.
3. In contrast, in a relatively small wind tunnel the streamlines ahead of the vehicle cannot diverge as far as they do in the open air, because they are constrained by the nozzle. This causes the effective wind speed to be larger than that intended; more so in fact, the shorter the distance between vehicle and nozzle.

These three effects prevail simultaneously and, in aerodynamic wind tunnels, are handled with corrections that are applied to the measured data after the test³. However, this method cannot be used in a climatic wind tunnel. Instead, the effective wind speed during the test should match the circumferential speed of the rollers (except of course when simulating head- or tail-winds).

In the Modine climatic wind tunnel, this condition is met by fine adjustment of the wind speed using the Pitot pressure method. The required wind speed is that which gives a pressure coefficient $c_p = 1$ at the stagnation point on the front of the vehicle. The total pressure p_0 in the stream ahead of the vehicle is measured with a Pitot tube. Care is taken that the Pitot tube is aligned with the local flow. This is ensured by positioning it with the help of a smoke-probe. The advantage of the Pitot pressure method is that for a given test setup (vehicle, distance from the nozzle, etc.), a correction factor that is valid for all speeds is determined with one single measurement of $p_0 - p_\infty$.

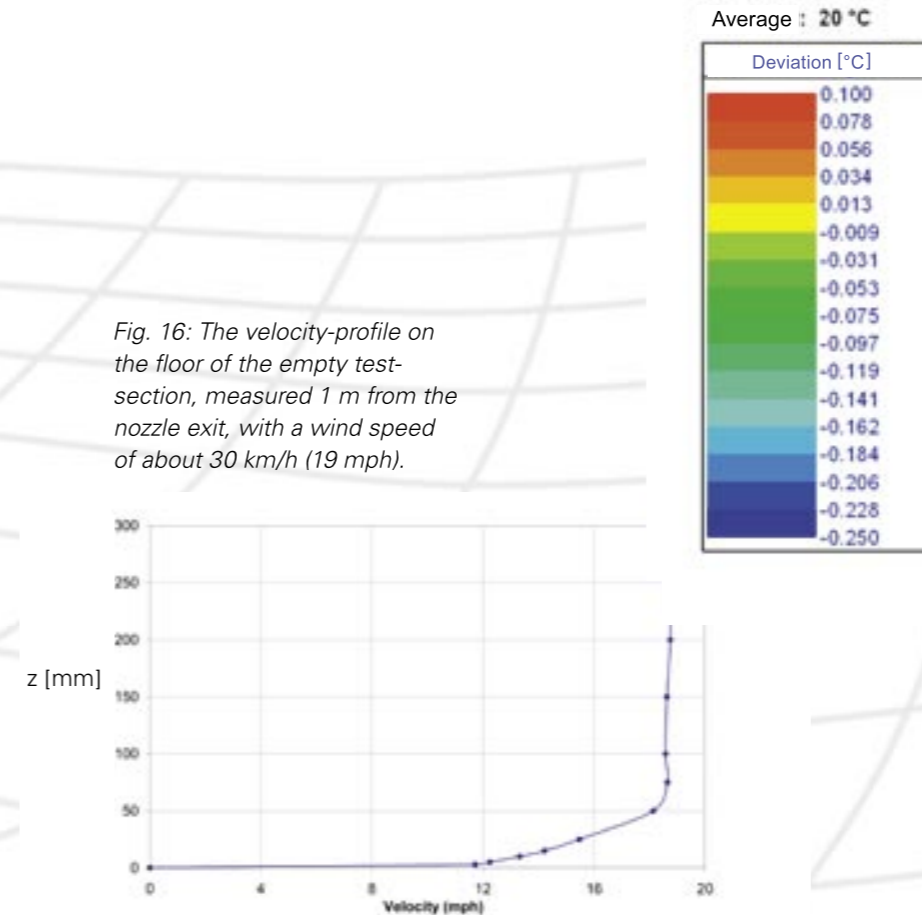


Fig. 16: The velocity-profile on the floor of the empty test-section, measured 1 m from the nozzle exit, with a wind speed of about 30 km/h (19 mph).

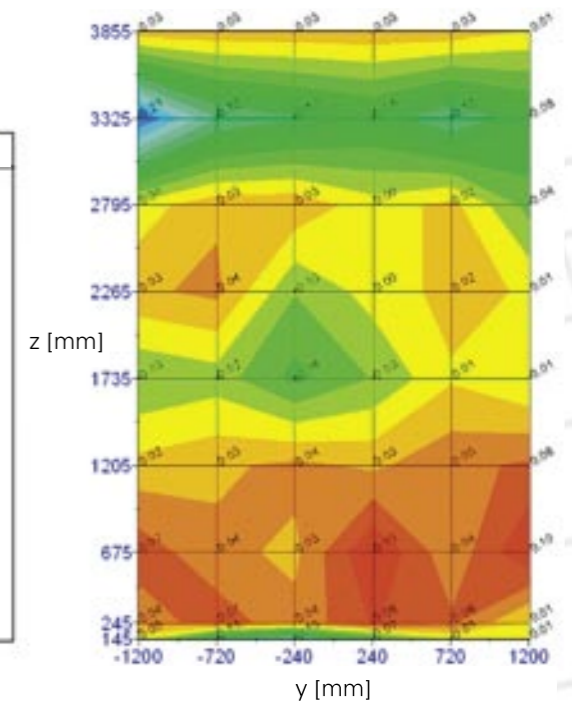


Fig. 15: Temperature-distributions in empty test section, truck nozzle.

³ See Merker & Wiedemann (1996)

Qualities of the Climatic Wind Tunnel

The velocity-distribution over the flow area was shown with the calibration of the nozzles. Furthermore, the turbulence-level is less than 1% for both nozzles⁴. The temperature-distribution over the flow area is - as shown in Fig. 15 - very even; the local temperatures deviate from the average value by less than 0.3°C. The static pressure along the empty test section is almost constant.

The velocity-profile on the floor of the empty test section is typical of turbulent boundary layers; at a wind speed of about 30 km/h (19 mph), the thickness 1 m behind the nozzle-exit is about 70 mm, see Fig. 16. This corresponds to less than half the ground clearance of a typical passenger car. Moreover, the airflow between the vehicle and ground - whether road or test section - is influenced primarily by the displacement effect of the vehicle-body; in comparison to the empty test section, the thickness of the ground boundary layer is drastically reduced⁵. Hence there was no need to reduce the boundary layer thickness artificially, for example through suction or even with a moving belt. Except for a very small region immediately above the wind tunnel floor, the flow beneath the vehicle is very close to that on the road. Consequently, the heat transfer of the vehicle is adequately simulated in the wind tunnel.

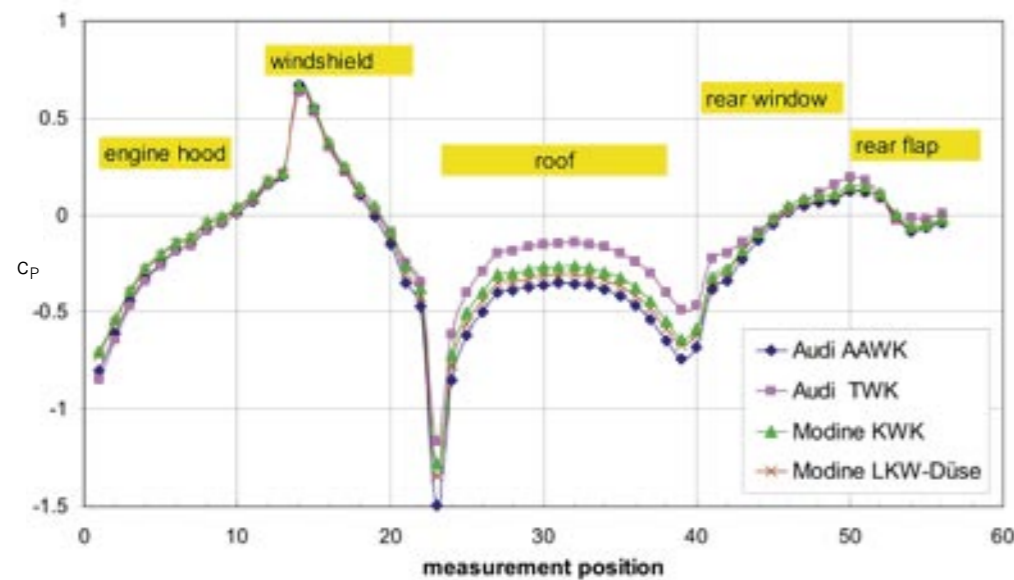


Fig. 17: Comparison of pressure distributions over a passenger car, measured in wind tunnels with different nozzle cross sections.



⁴ It lies far below the value of 3%, that - after Schwabe et al. (2002) - is allowable in climatic wind tunnels.

⁵ See Hucho (2005).

Comparison with other Wind Tunnels and with the Road

How well the airflow over a vehicle is simulated in a climatic wind tunnel may be shown by a comparison with that in an aerodynamic wind tunnel. This is done by measuring the pressure-distribution at certain points over the body surface. To avoid drilling into it, flat-probes (also known as "bedbugs") may be attached.

Such a comparison was carried out for a range of vehicles. The result for a passenger car is shown in Fig. 17. Compared with the values measured in the aerodynamic wind tunnel, both nozzles of the Modine wind tunnel give good agreement over the vehicle front end - affecting cooling tests - and a satisfactory agreement in the area of the passenger compartment - important for climate system tests. With a passenger car and the large nozzle, the agreement is even somewhat better. This was to be expected, since it gives a much smaller blockage ratio. Conversely, in a thermo-wind-tunnel with a nozzle area of only 3 m², big differences emerge downstream of the A-pillar. With a truck in the test section, the large nozzle gives very good agreement of the pressure distributions over the vehicle front end and the complete cab, including the underside. Only at the front edge of the roof do very small excess velocities occur, as shown in Fig. 18.

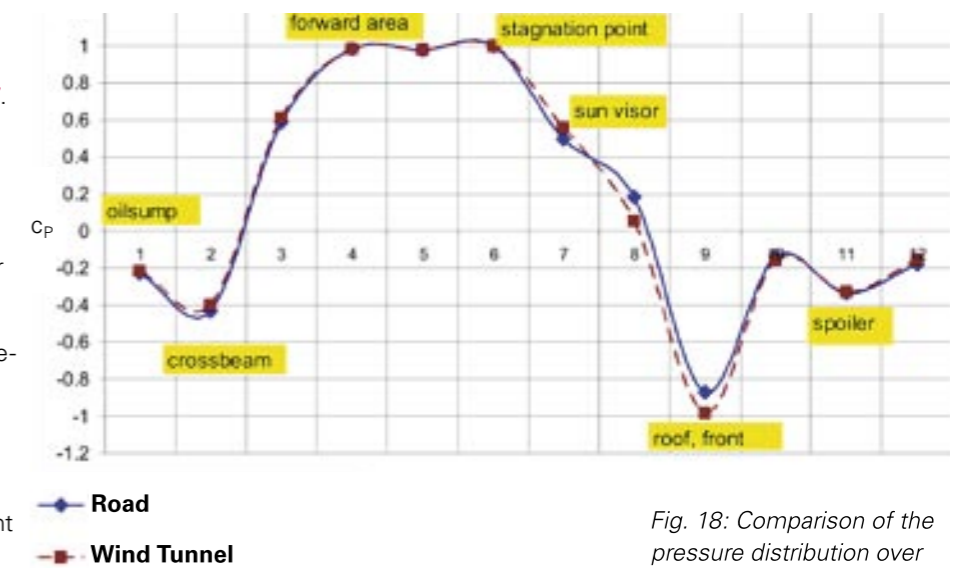
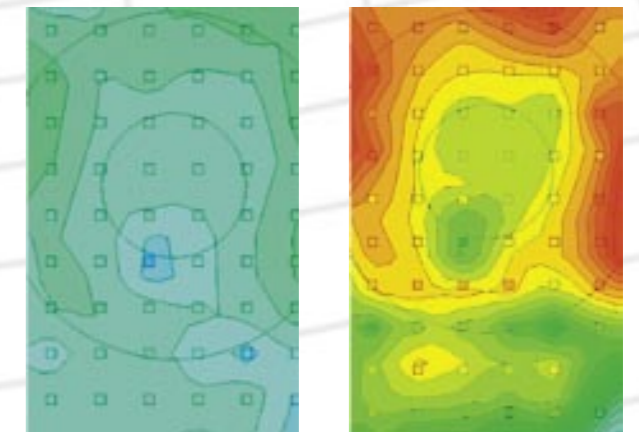


Fig. 18: Comparison of the pressure distribution over a truck cab, measured on the road and in the Modine climatic wind tunnel.

Tests in the Climatic Wind Tunnel

Before a vehicle thermal system is taken on field trials - summer and winter - it is tested in the climatic wind tunnel under all critical driving conditions, like maximum speed, hill-climbing with maximum trailer load, Stop and Go, etc. The object is not only to confirm the design performance data but also to explore possible improvements in function and cost.

Typical results for two such tests are shown in Fig.19. They show the air velocity distribution over the face area of a truck-radiator, presented as velocity contours. The effect of the fan is clearly visible. A uniform distribution of air velocity is sought, because the radiator is then best utilized.



fan at 1000 rpm
2400 rpm
Fig. 19: Distribution of face velocity over a truck radiator

The Climate Chamber

The Modine climate chamber is suitable for passenger cars and light vans. It is equipped with a roller dynamometer. The main dimensions and performance data are shown in **Table 3**.

Table 3: Climate chamber: Dimensions and performance data

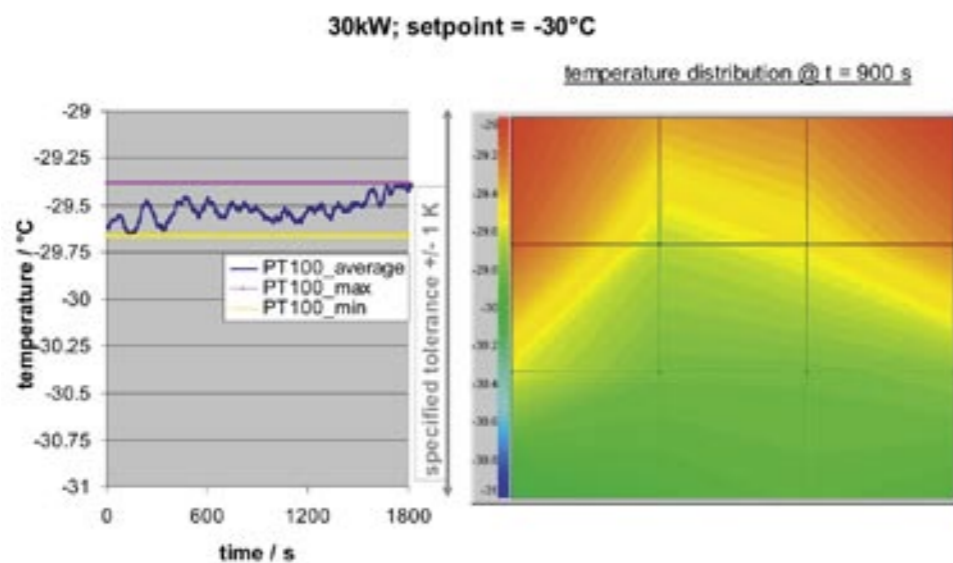
Size of the chamber	12 x 5 x 5 m
Temperature range	-30 to +55°C
Maximum cooling power	110kW at -5°C 30kW at -30°C
Maximum heating power	50kW
Relative Humidity	10 – 90%
Maximum dew point	43°C
Solar simulator area	6 x 2.5 m
Maximum solar radiation intensity	1100W/m ²
Maximum wind jet speed	120 km/h
Wind jet area	0.48 m ²
Dynamometer brake power	260kW
Roller speed	200km/h
Traction force	6kN
Axle load	2.5t



The climate chamber is equipped with two air systems: the one provides air change and conditioning, the other the wind jet:

- The air-change system is a modular unit, containing fans and heat exchangers, that extends over the whole width of the chamber; it is positioned below the ceiling. The air is discharged horizontally forward. At the front chamber-wall, it is diverted first downward and then rearward. Thus a gentle circulation is maintained. The supply and return flows are separated from each other by the solar lamp array. Altogether, the air flow rate is 60000 m³/h
- The wind jet fan sucks air from the upper part of the chamber and blows it towards the vehicle via a nozzle with a cross-section of 0.8 x 0.6 m at speeds of up to 120 km/h.

Fig. 20: Temperature distribution (over time, left, and cross-section, right) in the climate chamber in the cross-section at x = 4 m.



The temperature of the air is substantially uniform throughout the chamber-volume; an indication of this is shown in Fig. 20. On the right is the air temperature in the empty chamber over a vertical plane at x = 4 m. Furthermore, the stability of the air temperature is excellent; it is shown in the graph on the left. The maximum allowable spatial and temporal deviations of 1°C are certainly confirmed.

When testing, it is important how quickly a desired climate can be reached. The chamber itself can be cooled down from 55°C to -30°C within 140 min. However, for a vehicle, the specified pre-conditioning time is usually substantially longer, especially with low temperatures.

The relative humidity can be set at between 10 and 90%, with a maximum dew point of 43°C. Thus the control range corresponds to that of the climatic wind tunnel. Humidity is particularly important during air conditioning tests since high values increase the interior cooling load and can cause condensation to appear at the evaporator air outlet.

The position of the solar lamp array is adjustable both longitudinally and vertically. Moreover, the lamps are arranged in two panels, of which the forward can be swung down to simulate solar radiation from ahead, see Fig. 21. The radiation intensity can be dimmed between 1100 and 500 W/m².



Fig. 21: Solar-simulation, active area 6 x 2.5 m, radiation-intensity 1100 W/m², with stepless dimming to 500 W/m².



Tests in the Climate Chamber

A climate chamber may be used for many tests during the development of Heating, Ventilation, and Air Conditioning (HVAC) systems. As a typical example, the result of a cool-down test is shown in Fig. 22. The capability of an air-conditioning system is judged by - among others - how quickly the temperature in the interior of a vehicle decreases after the start. In the test shown, a tropical climate was simulated in the chamber: $t_0 = 40^\circ\text{C}$, $\phi = 90\%$, $I_{\text{Sun}} = 1000 \text{ W/m}^2$. In this case, a comfortable interior temperature, $t_i = 22^\circ\text{C}$, was reached after about 10 minutes.

Another type of test demonstrates the defrosting of the windshield according to FMVSS⁶ 103 procedure. The outside of the windshield is coated completely with frost before starting the engine. During the test, as the frost is cleared, a (here) red sheet, placed on the cowl top, becomes visible from inside the vehicle. The clearance contours are then traced on the windshield by hand every five minutes. An example result is shown in the sequence of photos in Fig. 23. Similar tests may be carried out to determine the clearance of mist from the inside of the windshield.

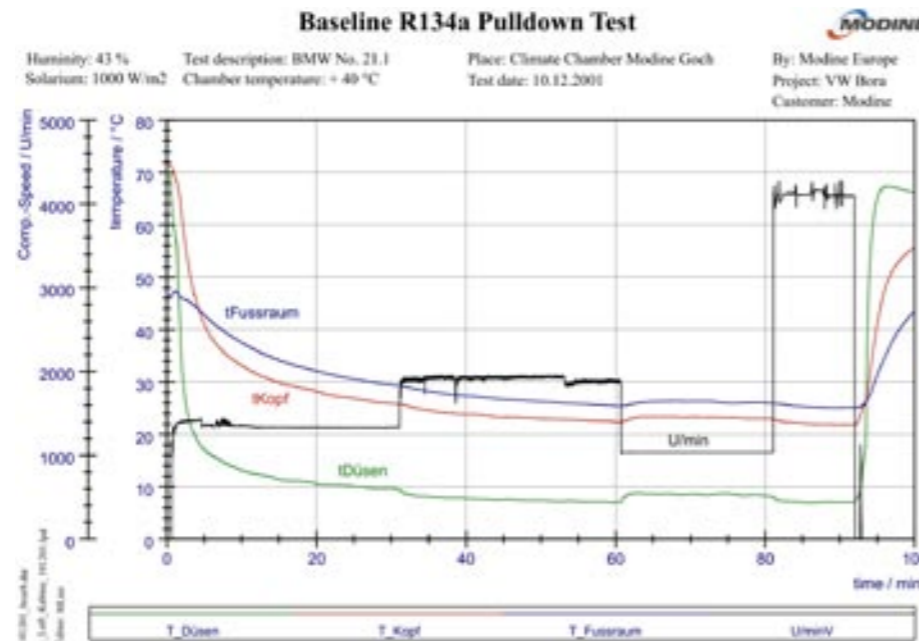


Fig. 22: Air conditioning 'Pull-down' test.

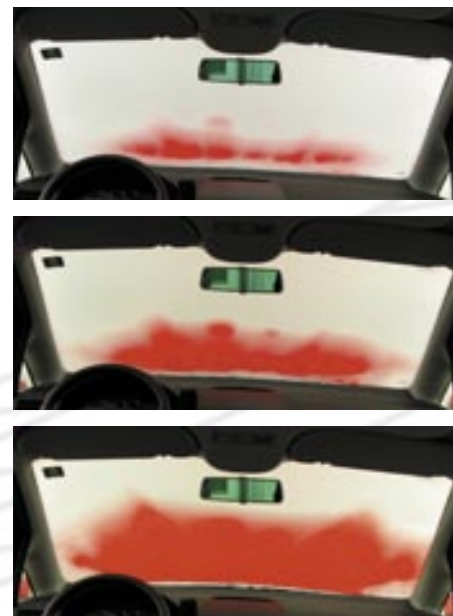


Fig. 23: Windshield defrosting after FMVSS 103. Air temperature $t = 0 \text{ F} (-18^\circ\text{C})$, engine speed 1500 rpm, no-load.



Fig. 26: Modine calibration vehicle.

Measuring Equipment

For both test facilities, efficient measuring equipment is available, including sensors for velocities, pressures and temperatures. A selection is shown in Fig. 24. The calibration of the sensors and the adjustment of the data cables is done with process- and pressure-calibrators, Fig. 25. The fixed measuring instruments are connected to the computers via a CAN-Bus. For a quick overview, hand-held probes with direct readouts may be used. Also external air flows can be rendered locally visible with a 'smoke-probe'.

To confirm that measurements in the climatic wind tunnel and in the climate chamber are equivalent to those on the road, Modine equipped a calibration vehicle with numerous probes for pressure and temperature measurement - as shown in Fig. 26. The agreement was good. The vehicle can also be used to perform correlations between different test facilities.

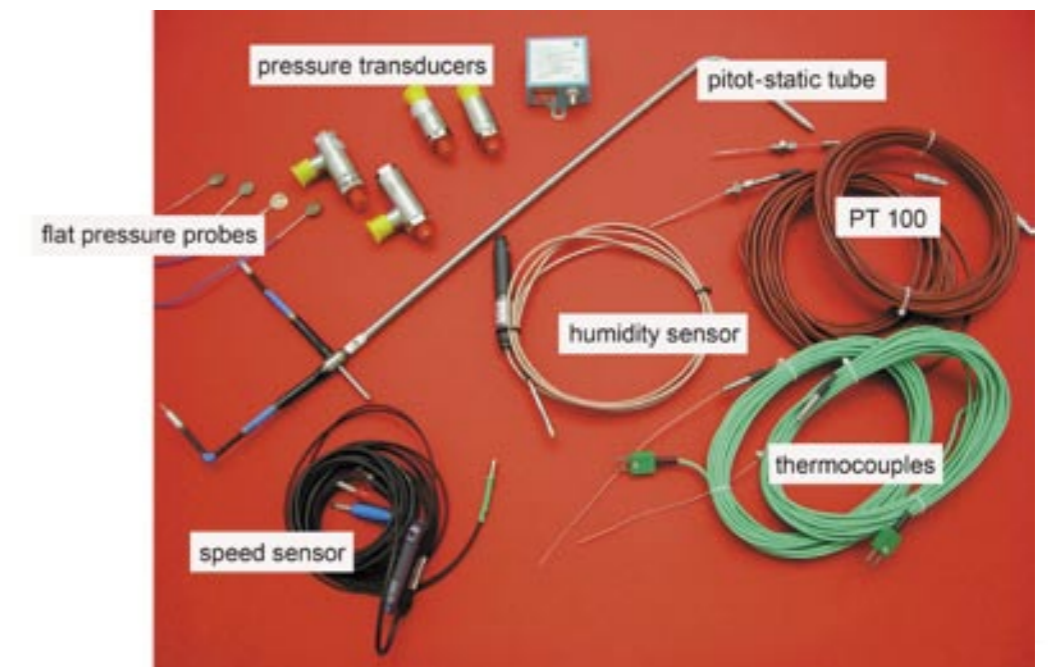


Fig. 24: Measuring equipment.



Fig. 25: Process and pressure calibrators.

⁶ FMVSS means Federal Motor Vehicle Safety Standard, statutory provision in the USA.

Measurement Data Collection and Processing

The data-management scheme is same for both test facilities, and is shown in Fig. 27.

The data from the test facilities, such as wind-speed, temperature, radiation-intensity and tractive forces at the rollers, are captured, processed, and displayed on the operating console and used as input values for the relevant control circuits. For the data from the test vehicles, there are two options:

- The users themselves provide the data acquisition and processing.
- The data are captured by the wind tunnel computer, processed, displayed numerically and graphically, further processed if necessary and stored. In addition, the raw data are archived.

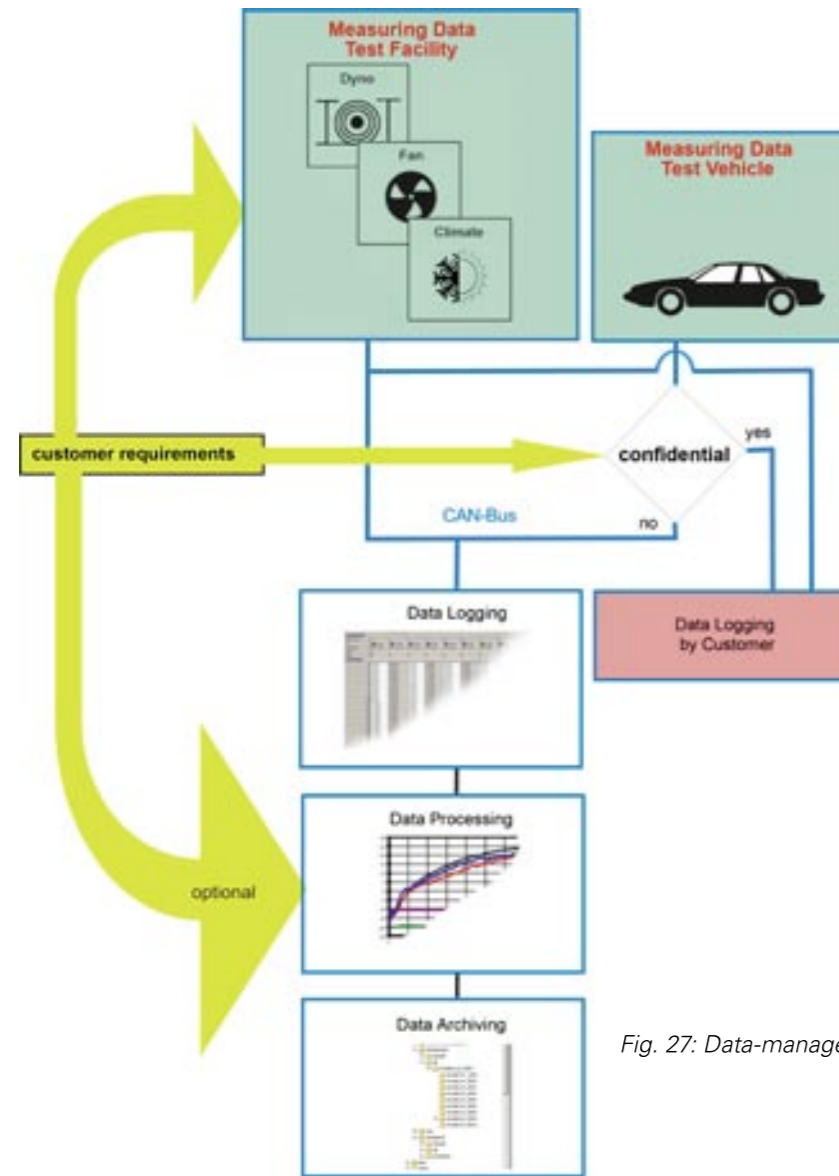


Fig. 27: Data-management, schematic

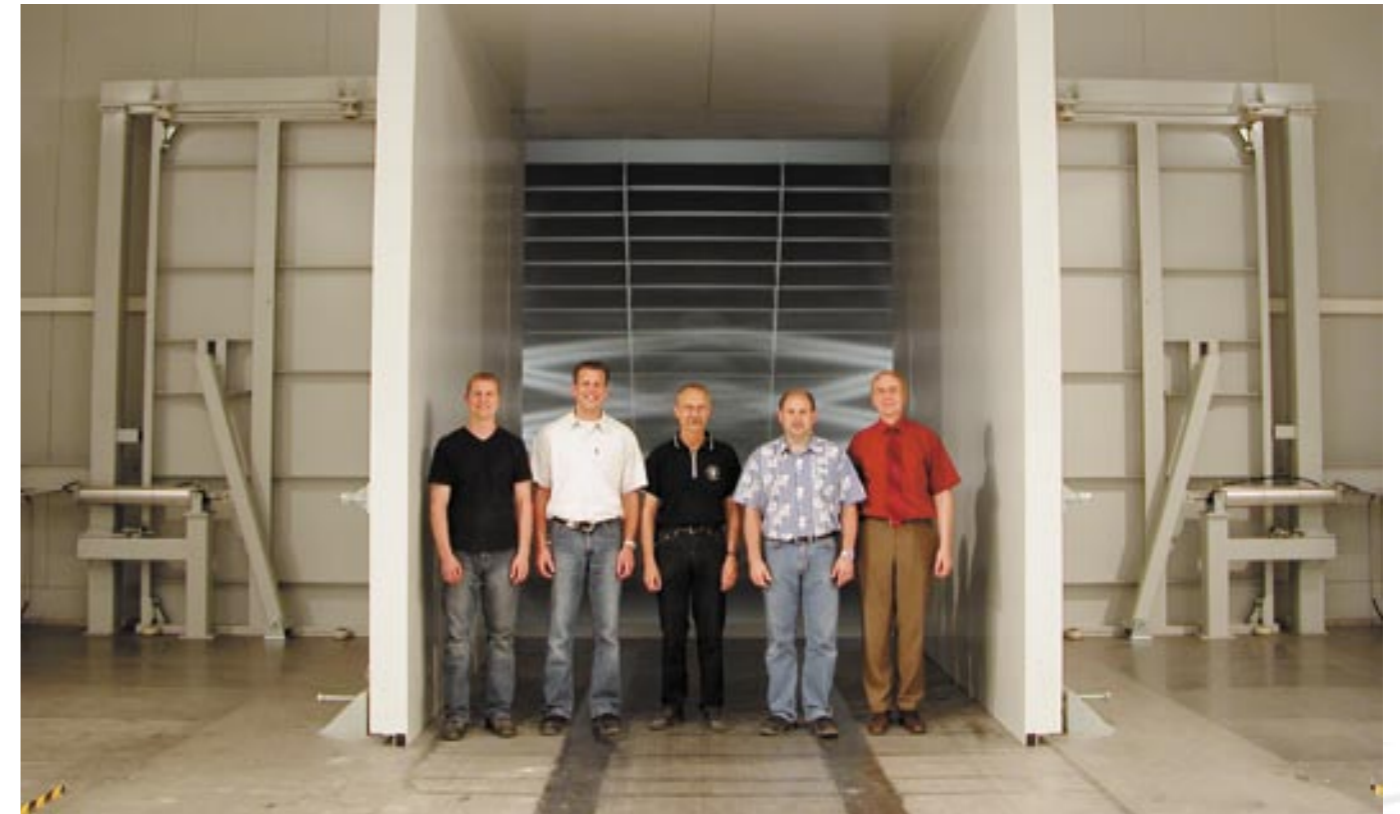
Booking the Climatic Wind Tunnel and Climate Chamber

The Modine climatic facilities in Filderstadt-Bonlanden may be used in various ways. As well as internal departments, the users can be external companies. The facilities are accredited according to ISOTS 16949.

Our wind tunnel team can take on any technical challenge. With creativity and flexibility we will focus on fulfilling customer demands and exceeding your expectations.

The terms of trade (standard terms and conditions, secrecy) as well as a price list are enclosed.

The contact addresses are shown on the rear cover.



Workshop

A workshop is located in the same building as the wind tunnel and climate chamber.

The main work area is equipped with lifts for passenger cars. Additionally two separate garages with crane and installation pit are available. There are separate rooms for meetings and another office is available for customers.



Literature

MERKER, E.; WIEDEMANN J. (1996): On the Correction of Interference Effects in Open Jet Wind Tunnels. Warrendale, Pa.: SAE-Paper 960671

SCHWABE, D., PAPPENFUSS, H.-D., DOEGE, K. (2002): Influence of Freestream Turbulence on Heat Transfer to Passenger Cars in Climatic Wind Tunnels. Warrendale, Pa.: SAE-paper 2002-01-0505.

HUCHO, W.-H. (Ed. 2005): Aerodynamik des Automobils. 5th Edition, Wiesbaden: Vieweg-Verlag (Aerodynamics of Road Vehicles, 4th edition. Warrendale, Pa.: SAE)

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