Introduction of the Super Small Tunnel (SST)

Yoshi Suzuka, Suzuka Racing Svc.

Very accurate and very useful
A smart tool for design the automobile.

Photo 1: Super Small Wind tunnel

Automotive aerodynamic development is important for safety, performance, and the environment. Development can also demand substantial costs. Major automobile manufacturers must manage the level of aerodynamic development with available budget. More progress can be made with less effort and in less time when superior tools are available.

As an experienced Aerodynamicist, I have spent countless hours testing in $1/10^{th}$ to full size wind tunnels at over 15 different sites, in several countries. Some of the wind tunnels had a rolling road belt and some had a fixed floor. Some were accurate and well designed and some were not. This resulted in my accumulation of over 30 years' experience developing wind tunnels as an efficient and practical development tool.

Low cost, quick turnaround operation and accuracy

It is possible to have accurate aerodynamic test data without a large investment in test equipment. When the wind tunnel and model size are reduced by half, the cost is reduced to 1/7 to 1/8 of the full size cost. When the wind tunnel's throat size and speed is reduced by half, the power requirements of the tunnel is reduced to 1/32 of the full size requirement. This geometric reduction in cost and power requirements continues as the wind tunnel size is further reduced.

Reducing the scale of the wind tunnel does not significantly reduce the measurement accuracy. With experience it is also possible to include an adequate cooling system in a very small wind tunnel. Testing with 10%, 14%, 20%, 25%, 33%, 40%, and 100% wind tunnels have proven each scale has its own pros and cons. The ideal situation is to test in all three; full, medium, and very small sizes. Testing with all three is often not possible when keeping within most project timing and budgets. For most projects the best economical solution is to have a small size tunnel and rent a medium size tunnel when it is necessary. This has been shown by the championship-winning cars I have developed using smaller wind tunnels than the competitors. Because of the economic advantage of a smaller tunnel, more of the budget can be used for additional model changes and test cycles, resulting in the discovery of larger gains.

I developed all Nissan's Le Mans cars in a 14% scale wind tunnel. One of these, the R91CP, continues to hold the fastest top speed record at Le Mans that it earned 23 years ago. This record could not be held without the low drag design that came from the 14% wind tunnel. This shows that small wind tunnels work.

My recent development work with the Nissan R35 GTR (production car) was in 40% wind tunnels. A 40% model was essential for this project to survey numerous tiny details and to obtain high resolution data. In most race cars, the larger, higher resolution data is unnecessary since the ducting systems are separated from the internal flow of engine bay and floor bottom shapes, while the flow field of a production car is more complicated so model detail and high resolution data is more important.

Note *1: The ducting systems of the race car are separated from the internal flow of engine bay and floor bottom is shaped simply, while the production car's flow field is very complicated and need to be model all the details.

Super Small Tunnel (SST)

Over the last three years I have developed a small wind tunnel for the purpose of reducing development cost while maintaining high quality test results. A larger tunnel may be necessary to test detail, but this tunnel provide rapid and low cost testing. With such a tool, scheduling wind tunnel time becomes unnecessary, ideas can be quickly evaluated, and waste is removed from the development process.

Evaluating the Wind Tunnel Performance – these are discussed in the next section

1. Reynolds number effect on drag
2. Accuracy of the model
3. Lift or down force accuracy

NOTE:

- The SST is not equipped with a moving belt system (rolling road).
- BLT (Boundary Layer Thickness) is less than 2mm over entire car length.
- It is difficult to achieve accurate lift or down force measurements with the SST
- Experience in aerodynamic testing is required to judge the output.
- Training is available

---Test results and details---

Eco aerodynamics testing

Photo 2: Full scale Wind Tunnel
Comparison tests with a full scale.

Photo 3: Full scale Comparison Setup
Super Small Tunnel (SST)

The test results of eight different add-on items for a 1/18 scale (5.6% model) sports car in the SST and an identical full size car in a full scale wind tunnel were compared.

1. Verify the similarity of air flow of the frontal area

2.3.4. Verify the upper air flow toward the rear section

5.6. Verify the air flow near the floor boundary layer area

7. Vortex Generator (VG) to verify the under floor flow

8. Study the internal air flow of the car

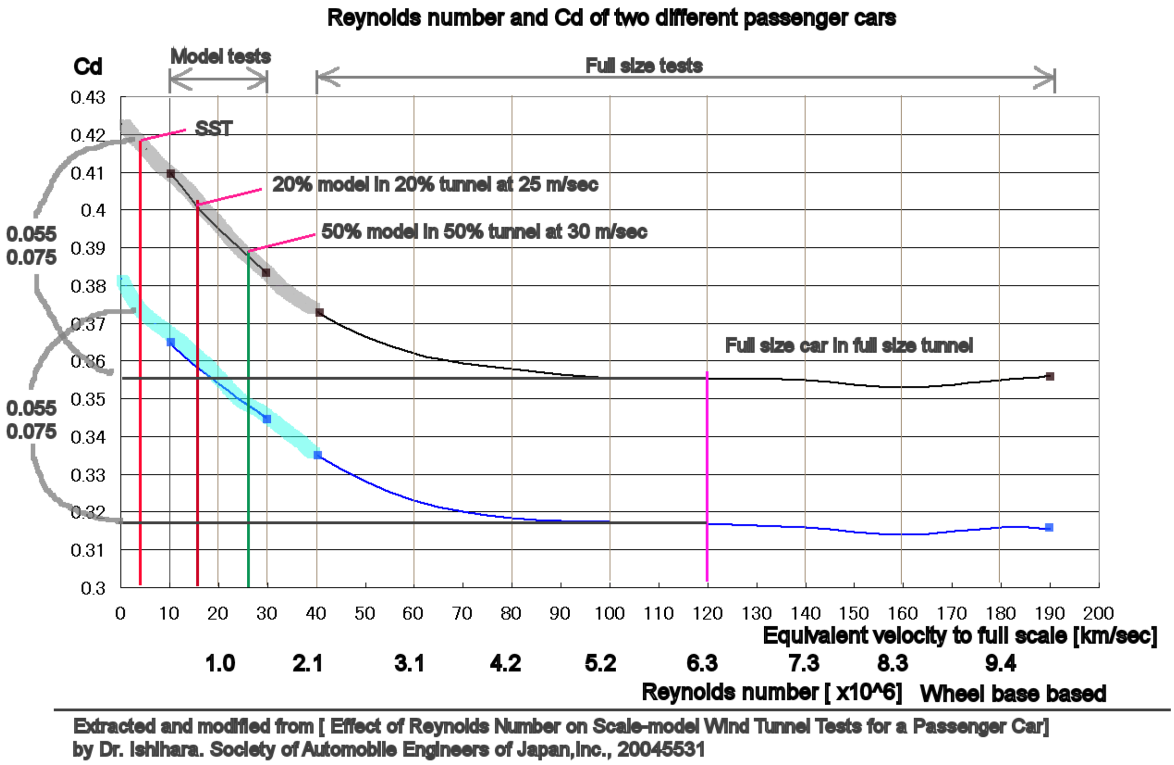
Assumption: Reynolds number

The study "Effect of Reynolds Number on Scale-model Wind Tunnel Tests of a Passenger Car" (SAE 20045531) by Dr. Ishihara of Nissan's Aerodynamic department documents the test result comparison of two types of cars with two different set up in a 20% and full scale wind tunnel.

The results indicated that the Coefficient of Drag (Cd) value of the 1/18th scale model can be estimated between 0.055 and 0.075 (55 to 75 counts) higher than full scale car's Cd value at over 120kph. Since the estimated crossing point is on the gradual extension line, we can conclude the data is reliable.

The vertical axis is the Cd value and horizontal axis is Reynolds number or equivalent full size speed in KPH.(1.61kph=1 mph).

There is no sudden change of Cd value (Critical Reynolds number) were observed in the comparison.



Graph 1-Reynolds Number

The graph shows the full scale wind tunnel results between 40kph and 190 kph. The slower speeds were created by the 20% scale models in a scale wind tunnel to cover lower Reynolds numbers.

The full scale wind tunnel is not able to run at air speeds under 40kph, therefore the 20% scale tunnel was used for this speed range.

There is a discontinuity in the graph where the 20% models do not contain the full detail as the full scale models. For example, the 20% models do not have rear view mirrors, engine compartment detail, accurately scaled door and hood seams, etc.

The Reynolds number of the SST is on the far right of the graph. The data comparison is made at 120kph rather than 190kph due to possible ride height change of the test cars due to lift or down force.

COMPARISON TEST

Below are pictures of the 1/18 scale model having the 8 different attached parts. The full size model had the same modifications.

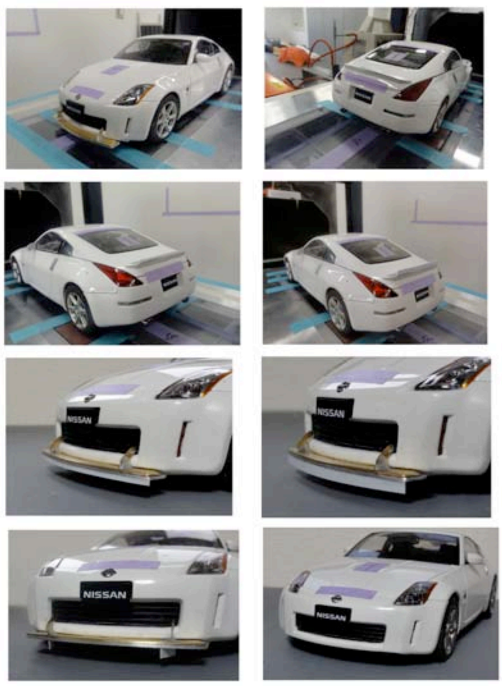


Photo 4: Model

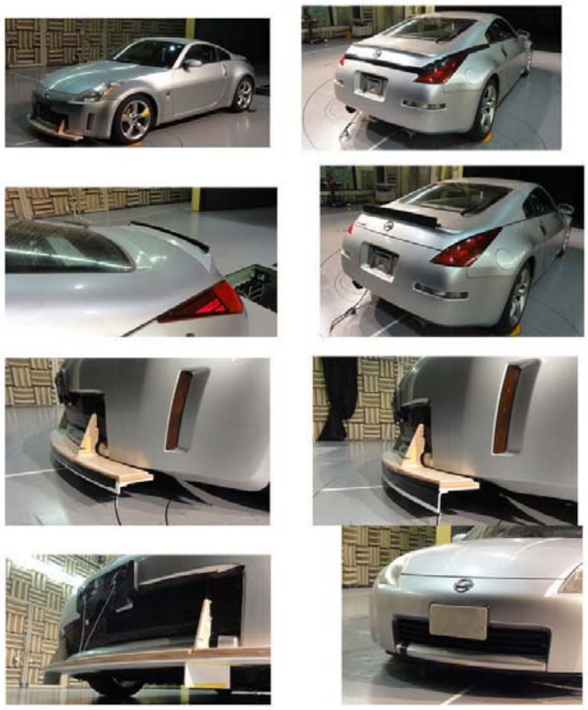
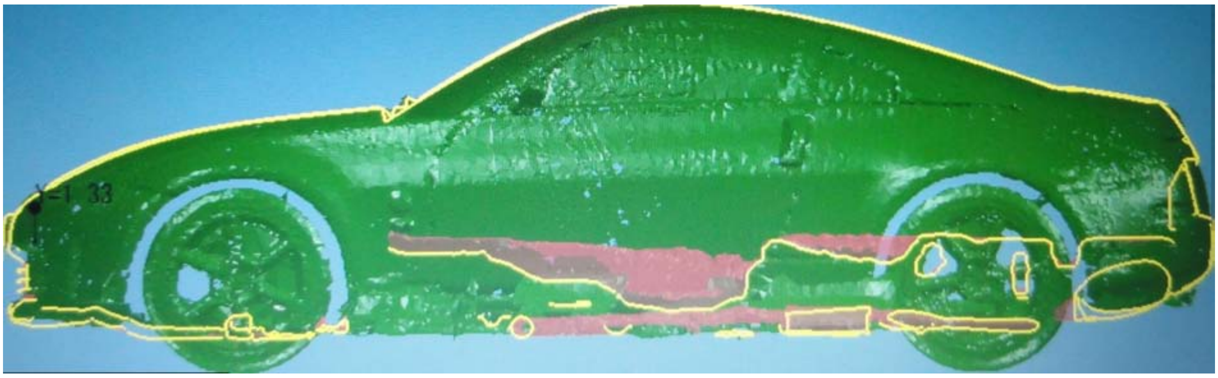


Photo 5: Full size test car

Model accuracy

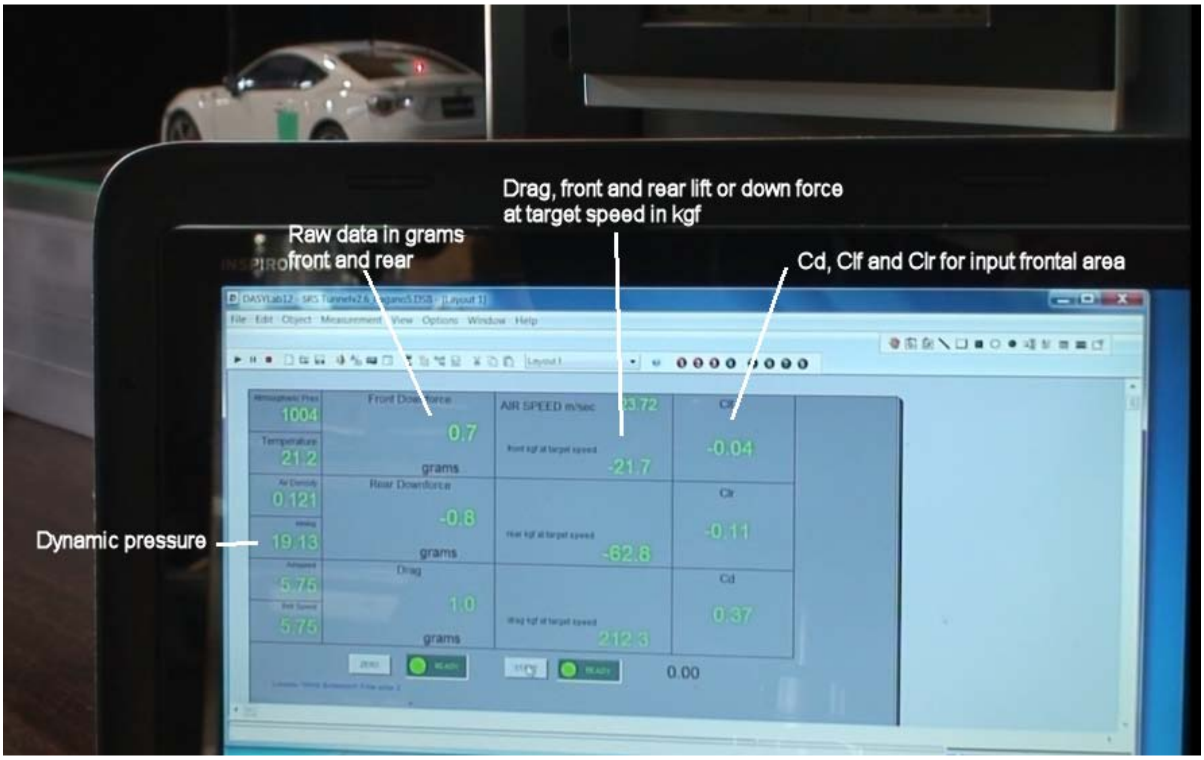
To verify the accuracy of the model, the 1/18 scale model and a full size Z car were scanned. After obtain the data, the model scanned data was expanded 18 times and laid over the design data of the production car.
Photo 6 shows that the two lines from production car data and the model scanned data are close to each other and almost indistinguishable. (Both lines are yellow).
The floor lines are also matched.
Only noticeable discrepancy is the front under-tray height location is miss matched, so it has been corrected.
This is a widely distributed AUTO-ART die-cast model.



Two yellow lines are drawn to the outline at vehicle center line.

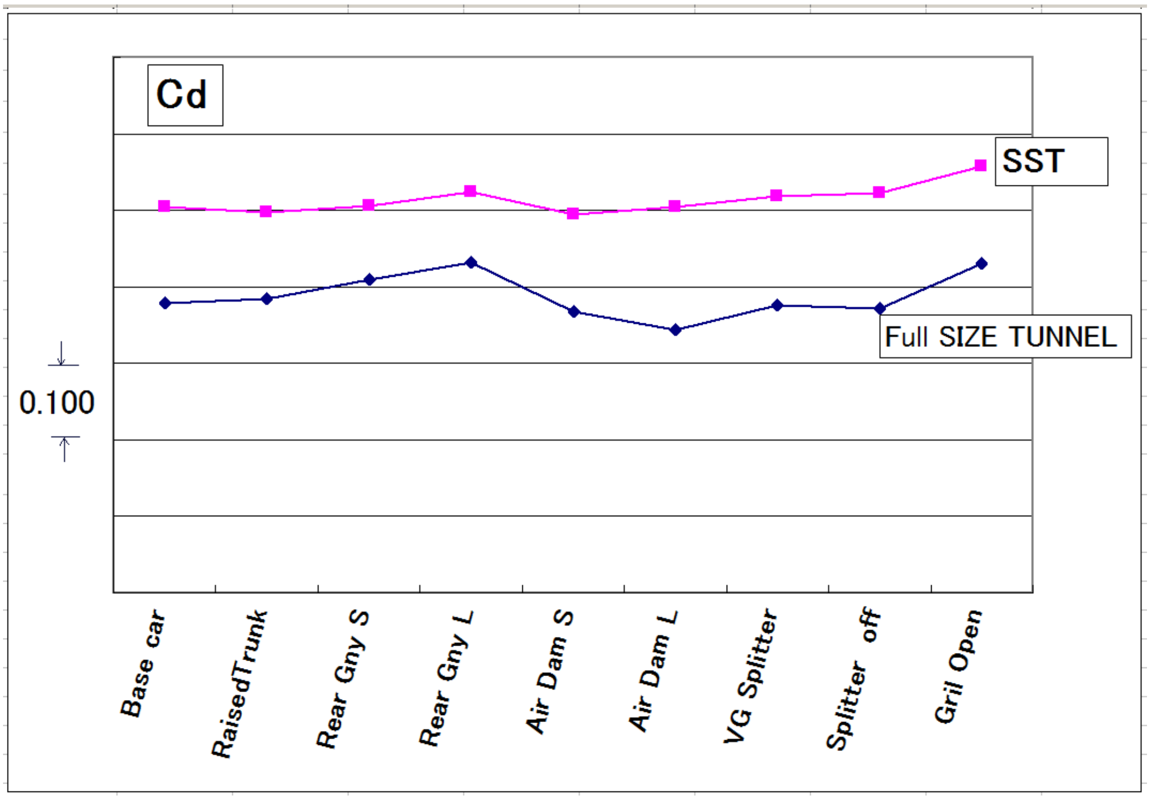
Photo 6: Two yellow lines are at a horizontal plane.

Photo 7: Computer screen of SST

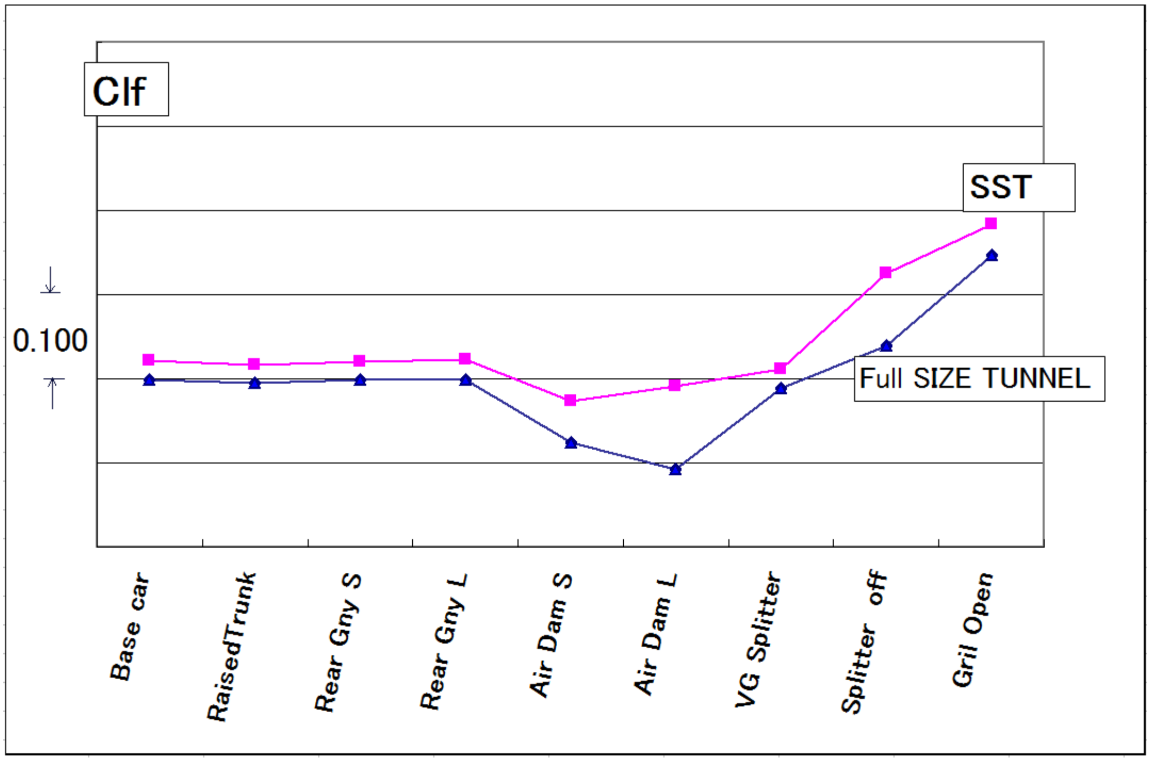


The test result –Matched accurately

Test item: Left to right, Base car, Grill closed, Front Splitter on, Raised rear trunk,
Gurney on rear spoiler, Air dam small, Air dam large and Vortex generator under front splitter.



Cd
SST
Full SIZE TUNNEL
0.100
Base car
RaisedTrunk
Rear Gny S
Rear Gny L
Air Dam S
Air Dam L
VG Splitter
Splitter off
Gril Open



Clf
SST
Full SIZE TUNNEL
0.100
Base car
RaisedTrunk
Rear Gny S
Rear Gny L
Air Dam S
Air Dam L
VG Splitter
Splitter off
Gril Open

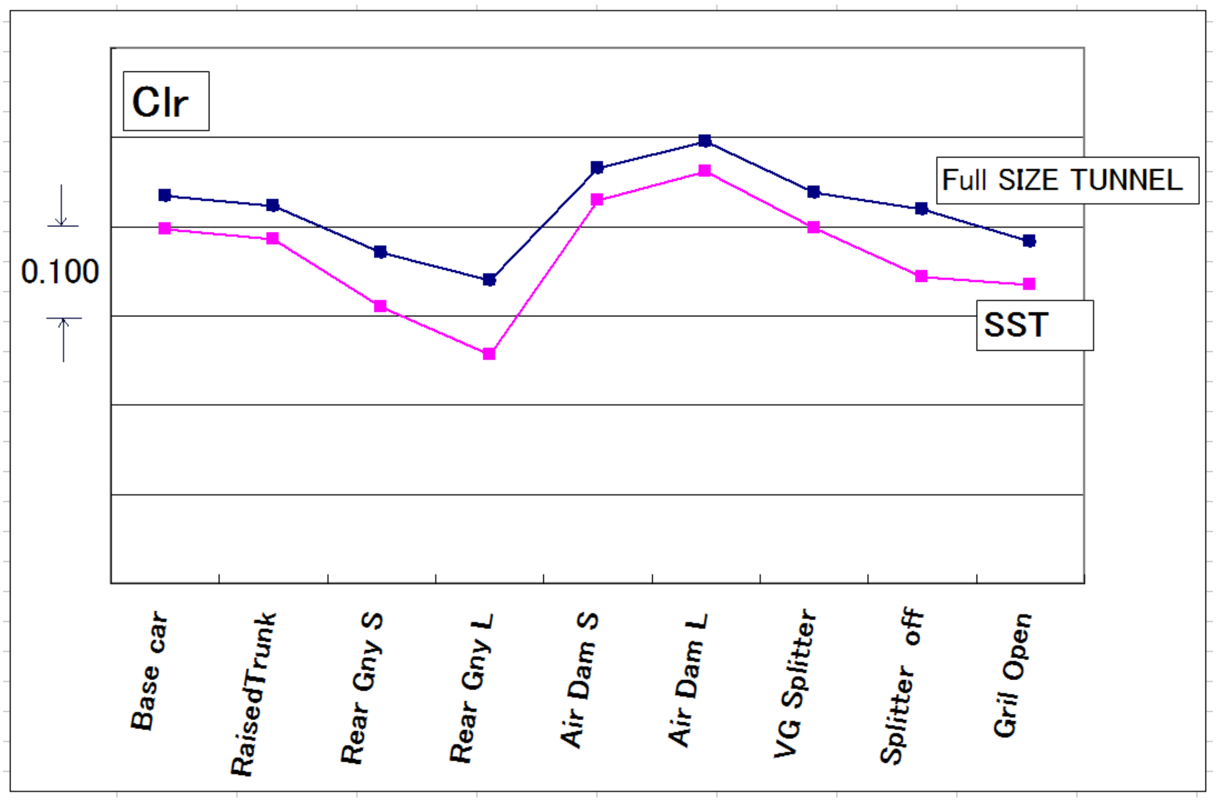


Fig 1: Test Results

Measured averaged Cd value was 0.063 higher than its full scale car as expected from the study of Dr. Ishihara.

All additional parts read out as the same trend as the full size car.

Test conditions

- Both wind tunnels have a fixed floor and semi-open configuration
- The turbulent factor is different between the two tunnels
- The distance and alignment of the test model from the nozzle are not equally scaled.
- The scaled Boundary Layer Thickness (BLT) in different between the two tunnels
- The static pressure buoyancy is different between the two tunnels
- The model used for the test was based on auto manufacturer's data and optically measured to verify accuracy.

- Some details are not exactly the same between the scaled and full size models.
- The scale model engine bay detail is simplified, affecting the internal flow.

Boundary Layer Thickness

The SST has an extraordinarily thin 2mm boundary layer over the entire length of the model without the help of a moving belt. This is equivalent to a 36mm boundary layer in a full scale tunnel

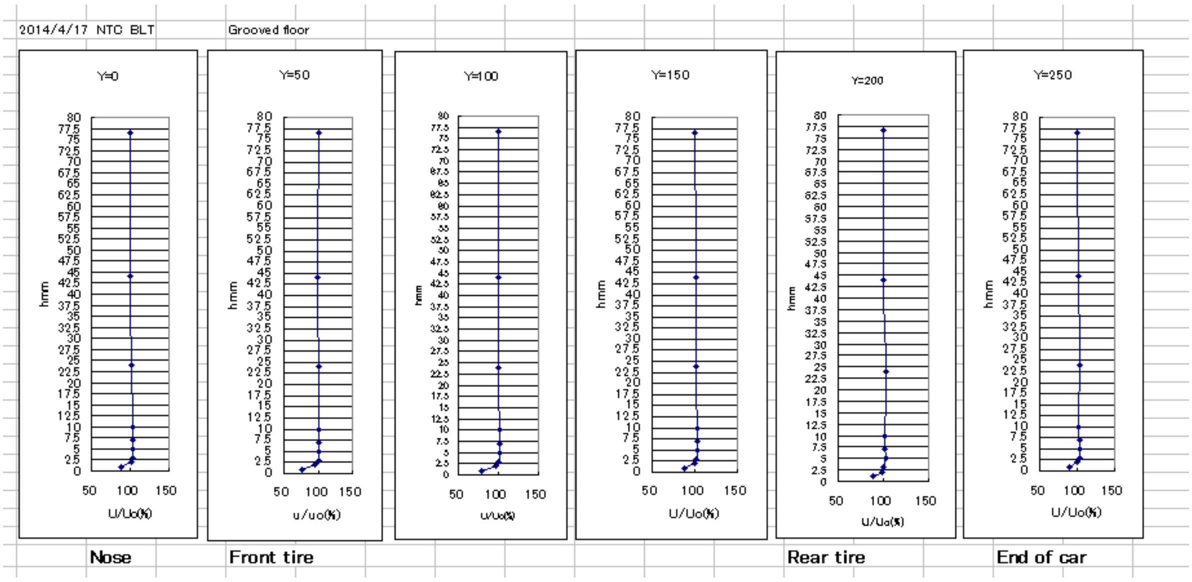
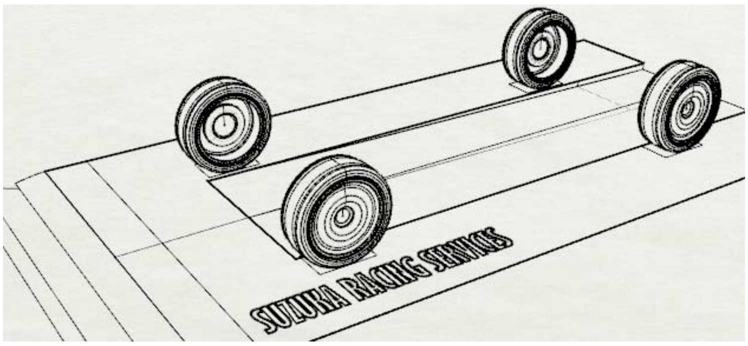


Fig 2: Boundary Layer Thickness



SRS BLT equalization floor

The Benefits of a Small Wind Tunnel

1. Low model tooling and fabrication costs
2. Low reoccurring costs, such as floor space, utility hookup, and energy costs
3. Rapid development process and reduction in waste of time and material
    a. 30 second setup + 30 second test replaces tunnel scheduling + 4 hour setup + 30 second test

   b. Smaller test parts that may be discarded require less fabrication time and material. They may be 3D printed rather than shop-built.
4. Commercially 1/18 die cast models made by auto manufacturers can easily be modified.

Comment

Contrary to some beliefs, many full scale automobile wind tunnels do not necessary produce accurate lifetime value.

The European Aerodynamic Data Exchange (EADE) reported test results from 15 full scale wind tunnels using 10 different full size cars. The report shows that correction data may be calculated to some degree, but the original measurement data result is different from tunnel to tunnel. The Cd measurement difference between full scale tunnels is as much as 0.020. In other testing, a very expensive 50% tunnel produced data 0.040 higher than actual value. Lift and down force values are difficult to repeat. This has been shown in one of the world's leading full scale tunnels equipped with a moving belt where the measurement results varied by 20%.

Of 15 different moving belt wind tunnels used in the last 30 years, all produce different measurement results. The key is to know the difference in the tunnel data to real running measurements. Therefore a correlation must be made from time to time. Once the correlation is obtained, repeatability is the next vital issue to address.

Small scale

Some aerodynamicists may be critical of a 1/18th scale model due to its size. The criticisms may be with two points

1. Is an automobile aerodynamically considered a "streamlined object" or "bluff object"?

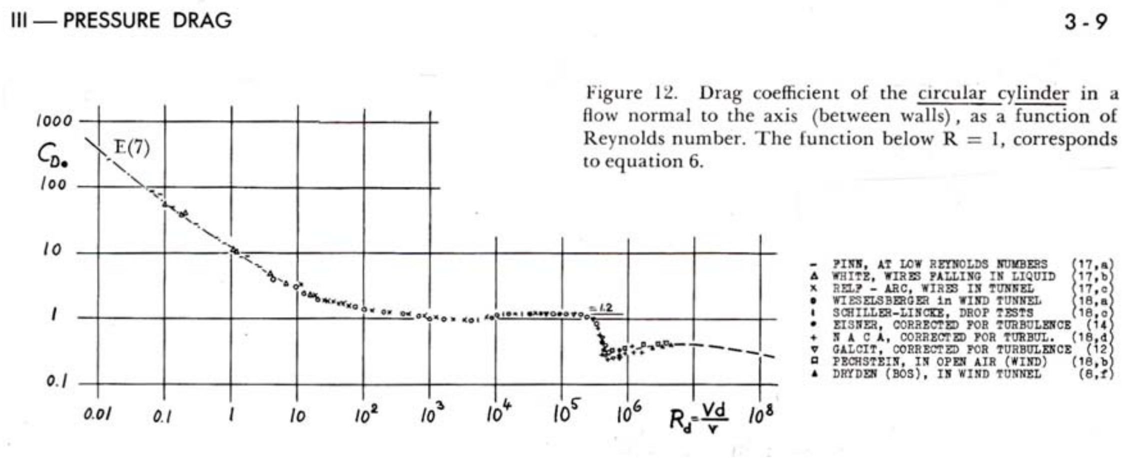
   In his test report Dr. Ishihara showed that a passenger car is considered a "bluff object" that does not have a critical Reynolds number.
2. Is the scaled model physically accurate?

The Akashi suspension bridge in Japan, at 3900 meters in length, is the longest span suspension bridge in the world. The bridge experiences strong winds in the annual typhoon season. The 1/100 scale bridge model was tested in a large purpose-built wind tunnel.

The Burj Khalifa is the worlds tallest building at 828 meters. A 1/500 scale model was used for testing.

This shows that 1/18 scale is not the smallest scale and can produce good results if models and equipment are accurately created.

Note: Additional information



*from Hoerner Fluid-Dynamic Drag

Fig 3: Cd vs Reynolds Number

A car body that appears smooth may still have poor aerodynamic performance, as it is essentially a Blunt Body “brick” not have a critical Reynolds Number. Most cars can be categorized as a blunt body.

Fig 3 shows the Cd vs Reynolds number of circular cylinder.
Between 10^5 and 10^6, there is a critical point where Cd drops from 1 to 0.5.
If the object under test has similar unexpected sudden change in Cd value like this circular cylinder, can not estimate if test at much different Reynolds number.
If it is a gradual curve, the values can be estimated even if tested at a different Reynolds Number.
Reynolds number is a function of the object’s inertia and the viscosity of the fluid.

Repeatability

Experienced aerodynamicists know the repeatability of the wind tunnel is equally important to its correlation.
The repeatability of the SST is approximately 0.3% for drag and 2-3% for lift and down force which is comparable to many multi-million dollar wind tunnels.

Because the SST does not hold the model with a stinger strut, mounting errors caused by flow leak through the stinger strut clearance gap or rear disturbances are reduced.

Specification

Read front & rear lift or down-force and drag force.
Fixed air speed.
Laser positioning.
Air bearing support.
A model weight should be within 0.6kg to 2.5kg. (1.5 to 5.5lbs)
Common 1/18 die cast scale model is around 0.6kg.
Wheel base of the full size car: 2.35 to 2.95 meter
Max outside track with of the full size car: 1.98 meter
Min. inside track width of the full size car: 1.1 meter
Custom tread and wheel base can be made.
Read Cd: 0.000, CLf:0.000 , Clr: 0.000
Yaw capability: SST is not designed to test at yaw condition, but you can yaw about one degree, depending on the model you test.

Power requirement

100VAC-115VAC, 50-60Hz, 8-10 Amp.
Different voltage is upon request.
Air supply is required: 7kg/sq.cm, 90PSI or 0.68MPa with minimum of 1 gallon tank.