February, 2002

DESIGN AND APPLICATION OF LOW SPEED WIND TUNNELS

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The goal of this article is to provide a short introduction to the design and application of low speed wind tunnels. These wind tunnels are designed to provide a well-defined, controllable, uniform flow of air for experimental and design validation purposes. While the low speed wind tunnel facility at the Galway-Mayo Institute of Technology (GMIT) was designed primarily to simulate forced air-cooling of electronic components and systems, examples are also provided to illustrate its application for the investigation of vehicle aerodynamics.

HISTORICAL BACKGROUND

Any introduction to wind tunnel design must acknowledge that the present understanding of the art has been developed primarily from aeronautical needs. Wind tunnels have been used widely to simulate airflow about complete aircraft, specific aircraft components, and to conduct fundamental research concerning flow phenomena related to flight for over a century (Prandtl and Tietjens, 1934; Baals and Corliss, 1981). The effectiveness of the wind tunnel was demonstrated by the Wright brothers, who developed their early wing designs using sub-scale tests in a small, low-cost tunnel. More recently, wind tunnel testing has become an integral part of the automobile design and development cycle (Hucho and Sovran, 1993), and has become routine for such applications as testing of atmospheric wind erosive effects and building-wind interactions. Some of the largest, most complex wind tunnel facilities operated by government, universities, and industry are catalogued by Penaranda and Freda (1985), while list of some larger, low-speed facilities is provided by Rae and Pope (1984). Still, the vast majority of the literature concerning wind tunnel system, as well as the commercially available wind tunnel apparatus, has been developed with a view to the particular needs of aeronautical research and testing.

However, wind tunnels are now finding use in non-traditional applications, such as simulating the forced airflows required to cool electronic systems. As the functionality of modern electronic systems increase, power dissipation levels also increase and forced air-cooling is required to maintain operating temperatures below preset maximum levels, so that reliable and safe operation is maintained. While fans and air blowers are typically used to provide this airflow, thermal designers require input data to aid the design process so that the thermal performance of electronic components, Printed Circuit Boards (PCBs) and heat sinks are known. Such empirical data is obtained using low speed wind tunnels and an excellent review of the issues surrounding wind tunnel design for such applications has been presented by Westphal (1997). The wind tunnel facility in use at the GMIT has been designed to meet these requirements.

GMIT WIND TUNNEL TEST FACILITY

i) Design : The requirements of wind tunnels used to simulate the forced airflows over electronic components an systems are listed in Table 1, along with the performance of the GMIT test facility. The GMIT facility shown in Figure 1, has a 300mm x 300mm test section, within which the achievable flow velocity ranges from 0.5 m/s to 12.0 m/s. At 12.0 m/s, this is equivalent to a volume flow rate of approximately 1.3 m^3/s [4,680 m^3/hr] against a pressure drop of 700 Pa. This capacity is provided by a Ziehl-EBM, MZ028 Fan, powered by a 2.2 kW motor. Speed control is maintained using a Telemecanique Altivar 28 speed controller.

***Table 1** : Requirements of Wind Tunnels used in Electronic System Cooling*

Parameter	Requirement [Westphal (1997)]	GMIT Test Facility
Air flow Velocity	< 0.5 m/s to 10 m/s	0.2 m/s to 12 m/s
Air Temperature	0 to +50°C	20°C to 75 °C at 5.5m/s, 0.5 m^3/hr [=30kW]
Test Section Size	Millimeters at Component Level to Meters at Electronic System Level	300mm x 300mm test section cross section by 600mm long
Measurements	Air velocity, air temperature, heat flux and flow quality / direction	Air velocity, air temperature, heat flux and flow quality / direction
Reynolds Number	100 – 10,000	7000 – 200,000*

***Note:** The Reynolds Number presented for the GMIT Facility has been calculated based on the test section hydraulic diameter, 0.3m.*

Airflow Direction (Air Inlet)

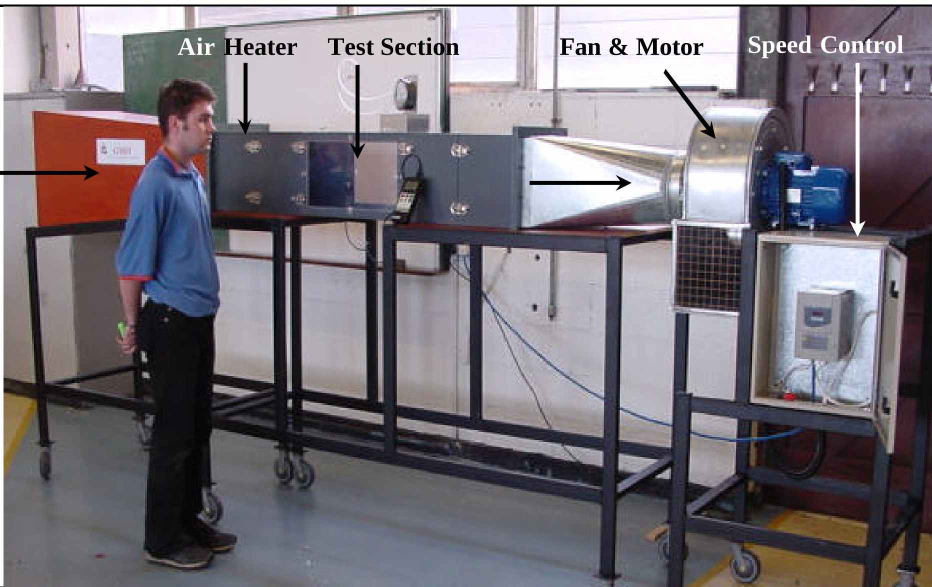


***Figure 1** – GMIT Wind Tunnel Test Facility (air is being drawing in from left)*

The quality of the airflow within the test section is demonstrated in Figure 2, where steady smoke streamlines indicate no swirl or turbulence in the free stream flow. Both features are undesirable and are designed out by using a series of design measures including the introduction flow straighteners and wire screens both upstream and downstream of the test section. The qualitative smoke flow measurements in Figure 2 have been supported by quantitative measurements of the flow velocity, which showed that a uniform velocity exists over the middle 280 mm of the 300 mm test section. A review of different flow visualisation techniques, including smoke flow visualisation, that can be applied to low speed air flows has been presented recently by Azar and Rodgers (2001) and the application of this technique is demonstrated in Figure 3 and 5.

***Figure 2** – Smoke streamlines recorded within the test section at a free stream velocity of 2m/s. Approximately 8 mm between each streamline.*

ii) Applications : Among others, the GMIT wind tunnel facility presented in Figure 1 is currently being used for the following applications.

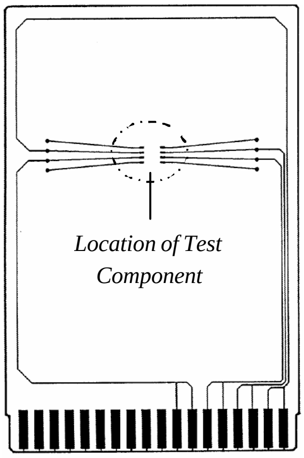
a) Heat Transfer – This low speed wind tunnel has been designed to measure the thermal performance of single, board-mounted components similar to that shown in Figure 3(a). While it is possible to conduct these measurements to international standards, recent efforts have been directed towards the characterisation of application type, multi-component PCBs shown in Figure 3(b). In addition to measuring component operating temperatures at different air velocities, effort has focused on visualising the complex flow fields about these component topologies, Figures 3(c), 3(d) and 3(e). These studies have revealed a highly complex flow field that is difficult to predict. As convective heat transfer rates are directly linked with these flow fields it is not surprising that prediction accuracy varies with the complexity of the flow fields. As a result, flow visualisation can be used to identify locations of greatest sensitivity and to aid the development of numerical modelling methodologies [Eveloy et al., 2000].

b) Flow Resistance – While the thermal performance of various heat sink geometries shown in Figure 4(a), can also be measured, it is common to record the resistance offered by these heat sinks to airflow. Such pressure drop measurements can also be performed, but using customised wind tunnel test sections, Figure 4(b), that allow the degree of by-pass flow to be controlled. An example of a fully assembled wind tunnel that accommodates one such customised test section is presented in Figure 4(c) and this can be compared with the standard tunnel in Figure 1.

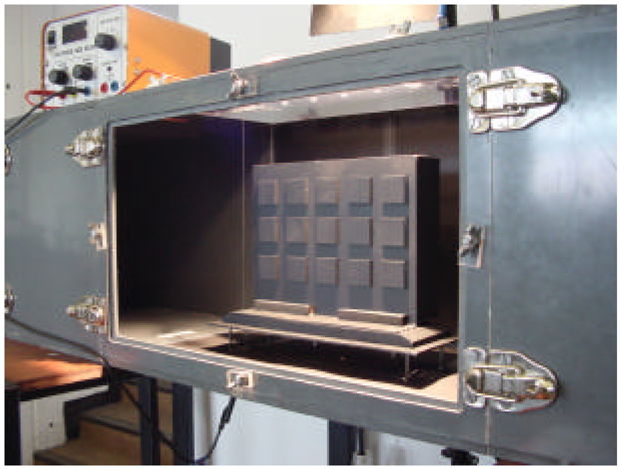
b) Aerodynamic Performance – While the air velocity range presented in Figure 5 are not realistic for a Formula 1 racing car, low speed wind tunnels can also be used to test the aerodynamic performance of slow moving vehicles. One such application is currently being tested at GMIT.

FURTHER INFORMATION

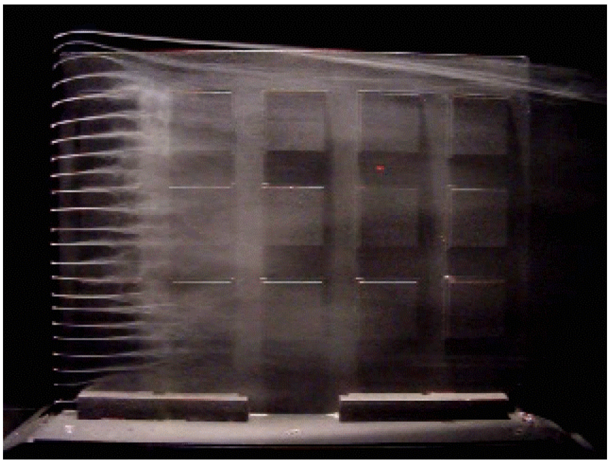
Further information on any of the material presented in this short article can be had contacting the author.



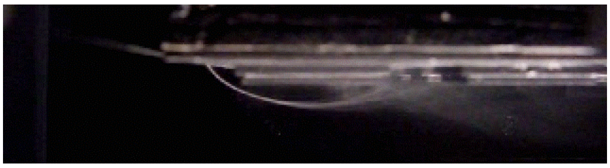
(a) Standard thermal test Printed Circuit Board, supporting one test component, in this case an 8-leaded SO-8 Package [Lohan et al. 1999]. The test PCB size is standardised at 76mm x 114mm.



(b) Multi-component test PCB located within test section. Hot wire required to provide smoke also visible upstream of the PCB's leading edge. Numerical prediction for this assembly has been presented by Eveloy *et al.* 2002.

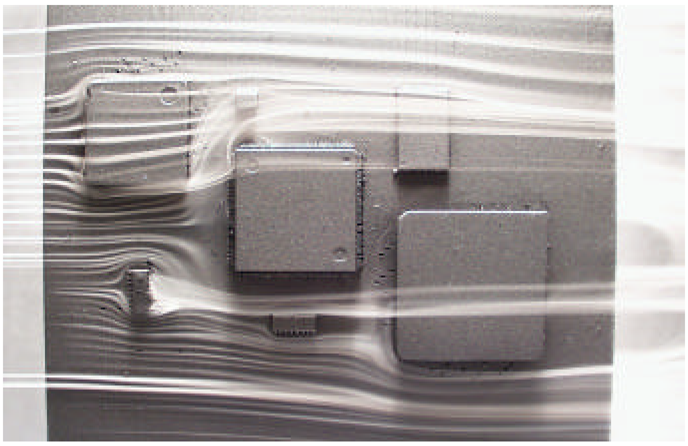


(c) front view of smoke flow over PCB shown in (a)



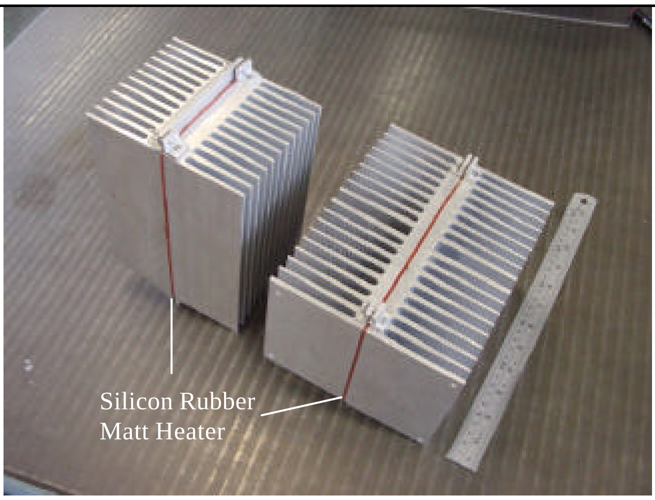
(d) plan view of smoke flow over the test PCB shown in (b) across

This flow shows the reattachment point where the streamlines impact onto the PCB surface, producing a region of high heat transfer. The complexity of this flow phenomena is difficult to envisage without experiments and also difficult to predict numerically.

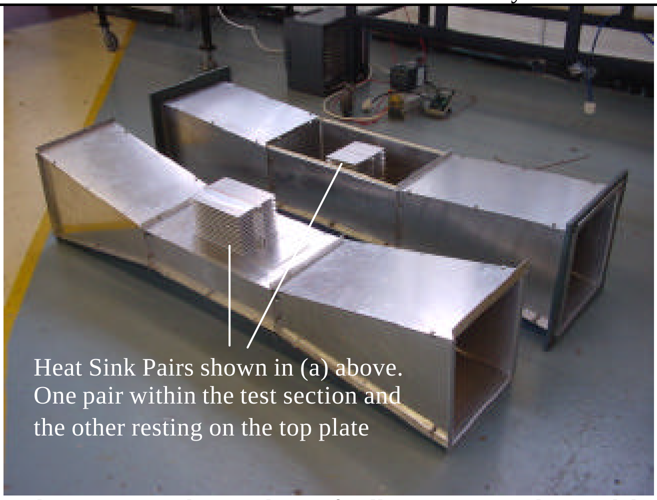


(e) smoke streamlines over a different multi-component test PCB to that shown in Figure 3(a) above, but these streamlines highlight the complexity of the flow fields that exist over the PCB [Azar & Rodgers, 2001].

Figure 3 *– Smoke streamlines over multi-component PCBs. Airflow direction is from left-to-right in all cases.*



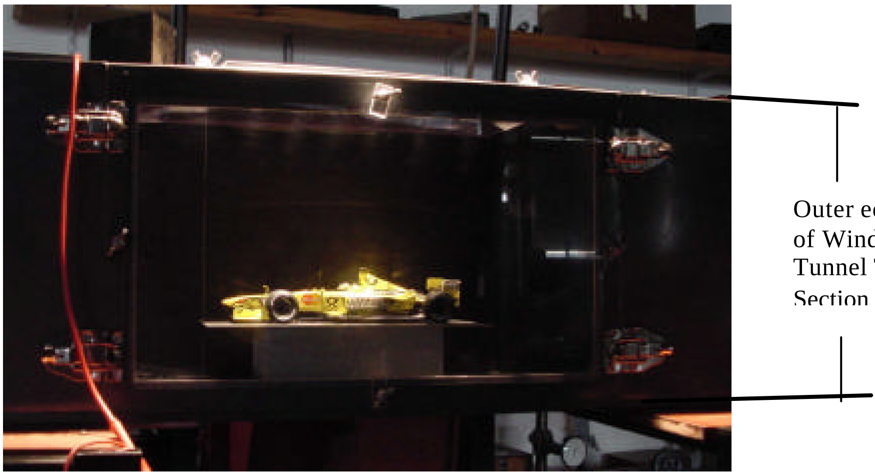
(a) Typical extruded aluminium heat sinks used for electronic system thermal management



(b) Customised test sections designed specifically to accommodate each heat sink size

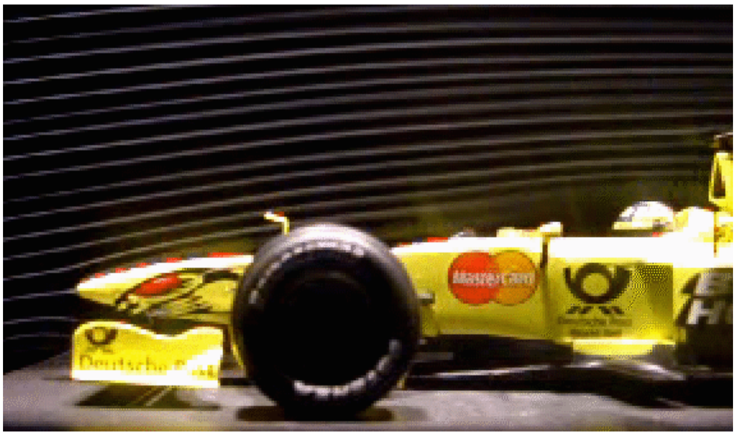
(c) Customised heat sink test section installed. Compare with Figure 1.

Figure 4 *– Customised test sections are used for heat sink thermal performance and pressure drop characterisation.*



(a) Model Car place within Wind Tunnel Test Section

(b) 5 m/s (18 km/hr)



airflow over body .

(c) 5 m/s (18 km/hr)

airflow over wheel .

***Figure 5** – Smoke streamlines recorded over a 1:18 scale model of a Formula 1 racing car. Airflow direction is from left-to-right in all photographs.*

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