ICAS-88-1.1.1 The views expressed in this paper are those of the author and not necessarily those of the Ministry of Defence, United Kingdom

SIMULATED ENVIRONMENT TESTING FOR AIRCRAFT

P.W. Smith
Engineering Division
Aeroplane and Armament Experimental Establishment
Boscombe Down, Salisbury, Wiltshire, England

1. Introduction

1.1. The Aeroplane and Armament Experimental Establishment in the United Kingdom is responsible for testing aircraft and associated equipments with the aim of recommending their clearance for Service use. In order to exercise this responsibility it is necessary to assess the operational performance of the whole aircraft under extreme environmental conditions of temperature, humidity, solar radiation, kinetic heating, rain and icing.

1.2. It is because the cost of overseas trials is high and such deployment does not guarantee either the desired ambient conditions or range of conditions that facilities were constructed to provide an alternative method of testing to overseas trials where appropriate.

1.3. Resulting from that conclusion 2 facilities have been developed to test complete aircraft (1) an environmental test centre and (2) an open jet blower tunnel. The environmental test centre covers the Arctic, tropical and desert temperature and humidity conditions. The blower tunnel covers the airspeed range of 10 to 340 kn IAS and incorporates an icing and rain facility.

2. The Natural Environment

2.1. Broadly speaking for an aeroplane, its instruments and equipments to operate world wide on the ground and during take-off the UK Defence Standard 970 and the US Military Specification 810 call for a wide climatic range which comprises the Arctic conditions of -26°C, the tropical zone of +50°C with 100% relative humidity and finally the dry desert condition of +70°C. Diurnal cycles of solar radiation up to 1100 watts/m^2 at +20°C and above are usually included.

2.2. Rain as far as military aircraft are concerned is described as moderate, heavy or very heavy with precipitation intensities of 415 and 40 mm/hr and corresponding droplet diameters of 1.0, 1.5 and 2 mm.

2.3. Aircraft icing definitions are grouped under 4 main headings, Instantaneous Maximum, Intermittent Maximum, Continuous Maximum and Freezing Rain. The temperature range is 0 to -40°C and the liquid water content 0.15 to 5 g/m^3. The droplet size range is from 20 to 30 microns volumetric median diameter.

3. Description of Facilities

3.1. Environmental Test Centre

This facility has been developed using a conventional hangar to provide simulated climatic conditions of the natural environment. To simulate Arctic extremes a special insulated test chamber is constructed inside the hangar up to 18.5 m x 16 m x 4.5 m high. Refrigeration is provided by spraying liquid nitrogen at -195°C into air drawn off from the chamber which is then re-circulated to cool the test subject. Stabilised temperatures of -40°C can be maintained for long periods and exposure to -60°C can readily be simulated if required. Personnel working in the chamber must wear Arctic clothing and carry oxygen equipment because of the additional nitrogen content of 15% in the atmosphere. Electrical and aircraft hydraulic systems can be checked using ground test rigs and conditioned air can be supplied to run environmental conditioning systems and auxiliary power units. The limitation of the cold facility is that engine running at sub-zero temperatures cannot be maintained due to the high mass flows of aircraft engines. Figure 1 shows a Tornado F3 in the sub-zero environment.

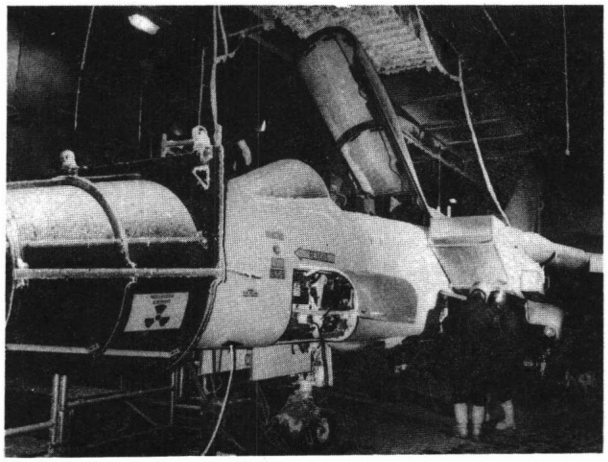

Fig 1. Tornado F3 in the sub-zero environment,

3.2. For high temperature and high humidity environments the full test area of 30 m x 30 m x 5.5 m high is available. Air heating is provided by 7 portable heater-blowers. Air is circulated around the periphery of the hangar leaving a central static region sufficient to accommodate an aircraft the size of Tornado for hot soak tests up to +75°C. Air temperatures up to +40°C can be sustained during test engine running with a mass flow of 72 kg/sec corresponding to the full range dry operation of one RB 199 engine.

3.3. Humidity in the hangar can be increased by injection of saturated steam to a capacity of 1840 kg/hr. This provides for an air make-up of 17 kg/sec at the maximum mixing ratio specified in Def Std 970 of 0.027 kg/kg at an air temperature of +30 to +35°C. Saturated environments can also be achieved to give cloud conditions. Conversely it should be noted there is no provision for decreasing humidity, that is, drying the air. Fig 2 shows an elevated temperature test of Jaguar.

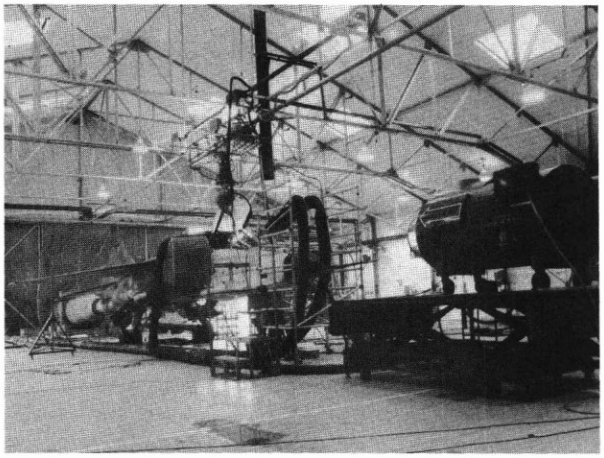

Fig 2. Jaguar. Elevated temperature test.

3.4. Solar Radiation

Simulated solar radiation has to cover the ultra-violet, visible and infra-red wavelengths. Tungsten filament lamps are used as the radiation spectrum is a function of filament temperature which typically varies proportionally with the applied voltage. Because of large transparencies used on aircraft a working area of 10 m^2 is used to assess air distribution and supply in cockpits. There are however differences between solar and simulated radiation. Usually the inner canopy temperature is considered the datum as the temperature gradient is usually large and therefore the conducted heat flow is also likely to be large compared to any absorbed solar heat. After establishing the datum temperature under natural conditions the simulated solar radiation is adjusted to give the same temperature letting the heating effect (watts/m^2) to settle to its own level. The differences between natural and simulated conditions depend on canopy thickness and material, eg a stretched acrylic, 13 mm thick will abosrb 20% of natural solar radiation and 40% of simulated. Fig 3 shows a Phantom undergoing a solar radiation test on its canopies.

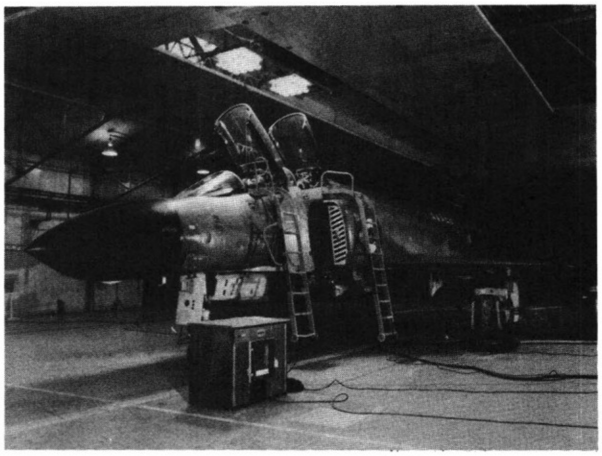

Fig 3. Phantom. Solar radiation trial.

3.5. Kinetic heating occurs on aircraft in motion. It becomes significant at high sub-sonic airspeeds and when the aircraft is flying low in relatively dense air. Calculations are based on the formula.

$$\text{Skin Temperature} = \text{Ambient Temperature} \times \left(1 + \text{Recovery Factor} \times \frac{\text{Mach Number}}{5}\right)^2$$

To simulate kinetic heating electrically- heated blankets are used, the blankets shaped to fit the fuselage and capable of producing temperatures up to 100°C and a maximum power of 1 kW/m^2. Thermostatic control is approximately 5°C about the selected value. Independent temperature elements are placed adjacent to the blanket thermocouples to provide a visual read-out. In Fig 4 a Jaguar is undergoing a simulated kinetic heating trial.

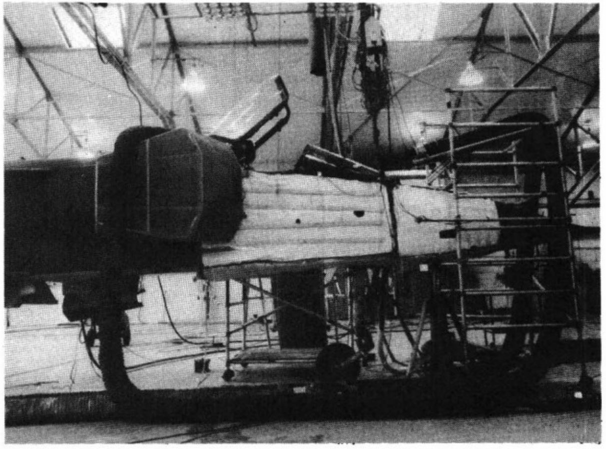

Fig 4. Jaguar. Simulated kinetic heating testing.

3.6. Engine Running

As indicated, auxiliary power unit running can be met with a conditioned air supply which takes care of both sub-zero and elevated temperatures. Because the facility has 7 heaters giving a combined output of 1.7 MW, temperatures can be maintained during engine running. However engine running cannot be sustained at temperatures lower than ambient and at sub-zero temperatures is limited to starting. Sub-zero engine running requires something like 20 times more refrigeration than current capacity, this topic is discussed later in this paper. The ducting of exhaust gases can lead to back pressure problems and damage to the APU or engine. APU ducting has a Coanda effect venturi built into it to reduce back pressure and fuselage skin temperatures to acceptable limits. Aircraft engine ducting is built with a generous expansion ratio and led to noise attenuators as shown in Fig 5.

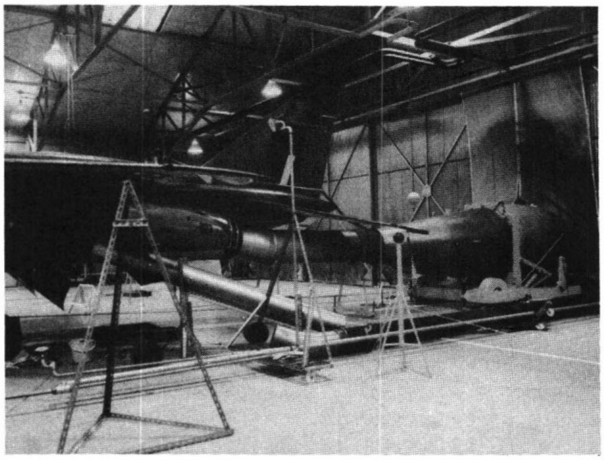

Fig 5. Aircraft engine ducting and attenuator.

3.7. The Blower Tunnel and Icing Facility

The Blower Tunnel is a facility where full scale testing can be carried out. Being an open jet tunnel with adequate space surrounding it complete aircraft can be positioned and restrained in front of the jet wich is adjustable in height from 2 to 5.4 m centreline datum and ±6° in pitch from the horizontal. The basic structure of the tunnel terminates in a 2.4 m diameter nozzle and different diameter exit nozzles can be added to cover the speed range 40 to 340 kn IAS in the following manner:

2.4 m nozzle diameter	190 kn	max airspeed
1.8 m "	230 kn	"
1.2 m "	290 kn	"
0.9 m "	320 kn	"
0.6 m "	240 kn	"

Fig 6 shows a view of the Blower Tunnel and the working area.

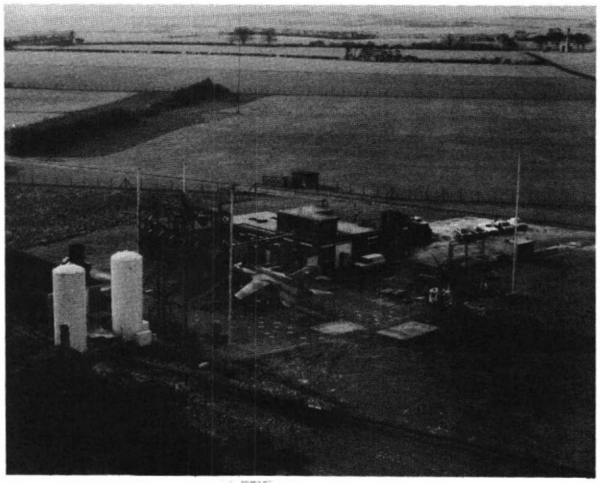

Fig 6. View of Blower Tunnel and working area.

3.8. An addition to the tunnel is the icing facility which is used to investigate the effect of ice accretion on aircraft surfaces, engine intakes and weapon systems. Direct injection of liquid nitrogen is used to reduce the airstream temperature and controlled water sprays give appropriate droplet sizes and concentrations, typically -10°C airflow temperature, 30 micron volumetric median diameter droplet size and maximum concentration of 3 grammes of water per cubic metre of air. The reduction of the airstream temperature is dependent on airspeed and exit nozzle size typical values being,

100 kn IAS	1.2 m nozzle diameter gives 30°C temp drop
100 kn IAS	1.8 m nozzle diameter gives 15°C temp drop

The amount of liquid nitrogen used for icing is large. A typical trial would consume 30 tonnes a day to give 30 mins of icing. Of course 30 mins of icing at continuous maximum gives large ice accretions and tests are usually limited to 3 or 5 mins.

3.9. It is usual to ice at approximately 100 kn in order to use liquid nitrogen economically. Then by calculation the effect of airspeed on ice build-up on aerofoil sections can be made, ie

$$K = 90.5 \frac{\rho o}{\rho} \frac{dD}{dc}^{2} \frac{d_c V\rho}{\mu}$$ See Fig 7

Ref. R.Ae.Soc. Vol 51

$$K = 90\cdot5 \frac{\rho_0}{\rho}\left(\frac{d_D}{d_c}\right)^2 \frac{d_c V\rho}{\mu}$$

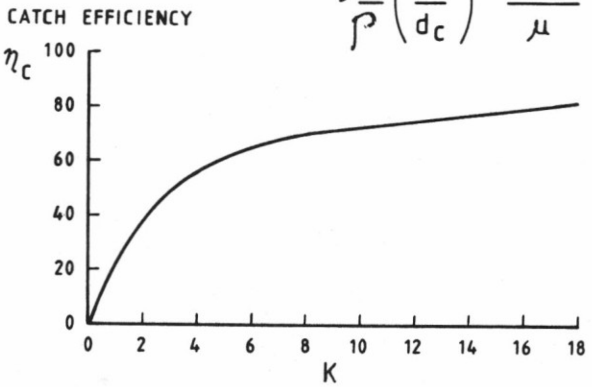

Fig 7. Water catch efficiency versus K factor.

The first term comprises a curve fitting constant and the ratio of sea level density to operating height. The second term is the ratio of droplet diameter to equivalent aerofoil cylinder. The third term is Reynolds number based on equivalent cylinder diameter. The catch efficiency is then read off. Ice thickness is calculated from:

Heat taken up by the water from air to aircraft surface + Heat lost to the air by conduction or convection + Heat lost to the air by evaporation

Fig 8 shows ice on the leading edge of an aircraft wing.

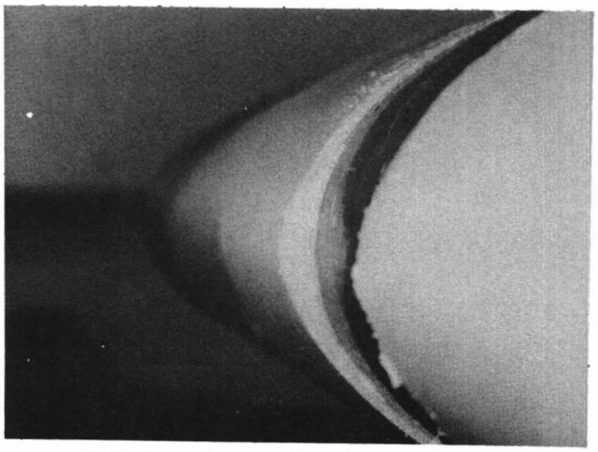

Fig 8. Ice on leading edge of an aircraft wing.

4. Rain

When simulating rain it is important to reproduce both the correct airborne water content and the characteristic drop size for any specified rain intensity. Water drops in a moving airstream do not survive if the relative velocity between the drop and the airstream exceeds a certain value, this value is shown in Fig 9.

Ref. RAE Tech Report 67245 1967

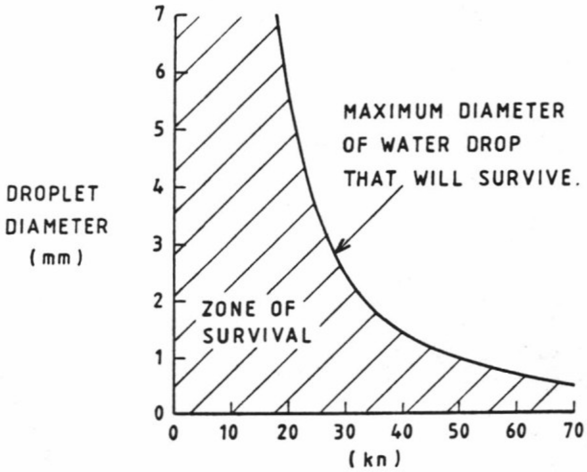

Fig 9. Disintegration velocities of water drops.

Thus the water is fed to the rain gun under pressure so that the difference between the water velocity and the airstream does not exceed the critical value. The rain gun is shown in Fig 10 and comprises 4 small bore tubes which form the 4 separate guns, the tubes forming the nozzles which are continuously oscillated vertically and horizontally by cams and electric motor at approximately uniform velocity producing a Lissajous figure to produce an even rain distribution every 2 secs over a 1.2 m^2 area. A range of tube diameters is necessary to cover various rainfall conditions and the tubes are therefore interchangeable.

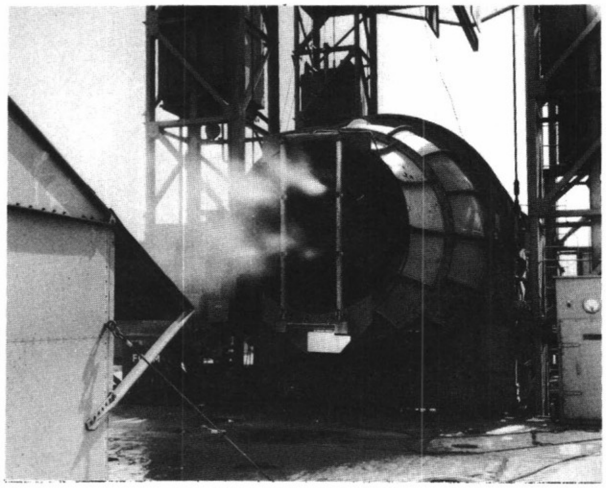

Fig 10. View of Rain Gun.

5. Instrumentation

The heart of the instrumentation system in the facilities is a computer-based data logging system located in the Environmental Hangar (see Fig 11).

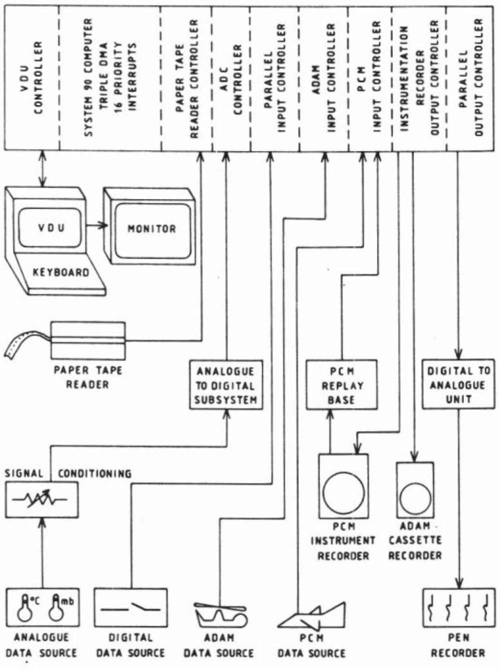

Fig 11. Data Logging System.

The data logger is used to collect and merge plant data with aircraft data and record it on a common tape of a replay system. An analogue to digital converter sub-system is interfaced to the logger to handle up to 40 analogue inputs from the plant. Interfaces are incorporated from ADAM and Base 10 aircraft data. Replayed data is taken through these same inputs via signal conditioning units. The operator console display is a cursor addressable 24 line Visual Display Unit with keyboard. It displays up to 20 selectable parameters as well as limit alarms as they occur. Software uses Coral 66 language to implement its commands. Data is input at a frame rate dictated by the type of aircraft under test. In addition to the aircraft data plant data is input via the analogue to digital converter and multiplexor channel. This is then validated and certain specified parameters are included in redundant or unused locations in the aircraft data frame. This modified frame is then output to the instrument recorder whilst additional monitoring of specified parameters is put to pen recorders.

6. Costs

6.1. Mention has been made in the introduction of this paper of the high cost of overseas trials being a significant reason for cheaper, simulated trials.

6.2. Costs have been calculated on a percentage basis after defining major items. Fig 12 shows that if the 3 major items defined in the overseas trial are added together the sum would be 100% which in turn is approximately equal to £¾ million. With the simulated case there are no subsistence charges or flying costs. There are however charges for the use of the facility, fuel costs for the heater-blowers and the liquid nitrogen used for cooling the aircraft. On the basis of comparable trials it will be seen that a simulated trial is costed at 37% of an overseas trial.

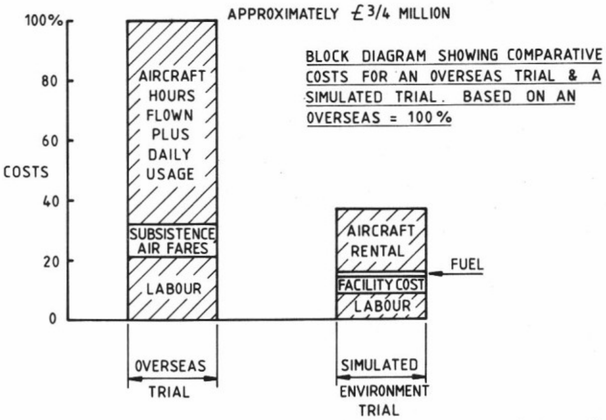

Fig 12. Comparison of Costs.

7. The Future

7.1. It is thought future investment could be best made in the provision of cold testing. Primarily this points to the air cooling rate which is currently insufficient for cold air make up to provide for sustained engine running. Beyond that the cold chamber could be made a permanent instead of a temporary structure and the mode of cooling which results in nitrogen enrichment of the atmosphere, changed. The refrigeration capacity would have to be considerable, currently liquid nitrogen flow rate at the Environmental Hangar is 0.4 kg/sec and for a typical engine mass flow of 72 kg/sec the liquid nitrogen flow would have to be 7.7 kg/sec.

7.2. A significant factor in air cooling for cold testing is the excess moisture which comes about as air is cooled through the dew point with relative importance depending on whether the test is at the soaking or engine running stage. The cost of plant for cold engine running and removal of moisture would be modest, approximately half of the money spent on the overseas trial example quoted earlier even when maintenance upkeep is considered.

8. Conclusions

The conclusions which can be drawn from this paper are:

a. The advancement of aeronautical development is enhanced by full scale simulated environment testing by its guaranteed conditions, its repeatability and its time saving by its independence from climatic seasons.

b. Because no flying is involved this method is inherently safe.

c. Cost effectiveness is the keynote of simulated testing at one-third of comparable overseas trials.

d. This form of testing is capable of development and can become more diverse and representative of natural conditions.