DESIGN AND OPERATION OF THE ADD ENVIRONMENTAL TEST FACILITY

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Abstract

The development of an Environmental Test Facility for the Agency of Defense Development of Korea is described, from its genesis, through design, to the commissioning and initial operation. This facility will provide a full test capability to validate prototype vehicle operation under extreme climatic conditions.

1 Introduction and Project Background

The Environmental Test Facility (ETF) is a major component of a new initiative to implement an indigenous aircraft development capability in Korea. The ETF is located adjacent to existing and planned test facilities at the Agency for Defense Development (ADD) Air Weapon Systems Test Center (AWTC) in Seosan AFB, near Hae-mi. The specific need for the ETF was to provide a full test capability to validate prototype vehicle operation under extreme climatic conditions.

The Boeing Company, as project financier, worked with ADD under the auspices of an Industrial Participation Program (IPP), also referred to as Offset, to synthesize the user needs into an affordable reality which fit within the Offset Program resource constraints. Aiolos, an international supplier of design, fabrication, and commissioning services of climatic and other facilities for global customers, provided all the climatic capability technology, while Boeing provided expert consultation from the perspective of a climatic test facility user.

Aiolos worked collaboratively with Boeing to define a total system consisting of a test chamber within a building such that ADD could assume responsibility for all aspects of the building and its subsystems, while Aiolos could do the same for the test chamber and all its subsystems.

This paper will begin with an overview of ETF requirements, and then describe the concept and key system features, highlight safety aspects, and present initial operation experience including commissioning results. Finally, some prospects for future enhancements will be given.

2 ETF Requirements Overview

The ETF has to serve essentially two environmental testing needs. The first is to show that large systems such as complete aircraft and their subsystems can be started up and come to fully functional status after an overnight “soak”. Also, it should be possible to demonstrate that all moving devices such as landing gear, flight control surfaces, hydraulic systems, etc. remain functional over their full range of motion in an operational climate, which simulates much of flight conditions except without altitude and aerodynamic loads.

The environmental simulation capability should enable test procedures which follow the MIL-STD-810F as far as practical. The range of vehicle types to be tested in the ETF includes:

- The largest aircraft in the Korean Air Force fleet, the CN-235 twin turboprop troop transport
- Other potential vehicles such as turbojet and turbofan aircraft, e.g. business jets and fighters, Unmanned Aerial Vehicles and full size land vehicles.

A summary of the climatic extremes possible in the ETF include: temperature -54°C to +54°C, with the ability to transition the entire range in 24 hours and operate a jet engine with make-up air over the temperature range -18°C to +54°C for 30 minutes every 24 hours; humidity 10%RH to 100%RH over the temperature range 20°C to +54°C; solar load 1120W/m^2 full spectrum over a reconfigurable 90m^2 footprint; rain 1 to 610mm/hour over a reconfigurable 140m^2 footprint; snow 75mm/hour over a reconfigurable footprint of 38m^2; wind 18m/sec over a reconfigurable footprint 9.3m^2.

3 ETF Concept

The model for the ETF was the largest existing contemporary facility in the world, the McKinley Climatic Laboratory Main Chamber currently used for domestic/international commercial and military vehicle climatic testing. The ETF design concept was sized for a much smaller footprint – 25% of McKinley's area to accommodate a CN235 – and was significantly evolved to meet the unique requirements of the Korean aerospace community.

3.1 Chamber Within a Building

The cost-effective solution to providing both a large chamber and a support building was to affect a "chamber-within-a-building" concept. This enabled an optimized approach to the structural integrity of the entire facility and a clear split of responsibility between Aiolos and ADD, as follows:

- The building supports the chamber and reacts all external environmental and chamber-induced loads
- The building supports the aircraft via a robust insulated hangar floor
- The chamber process equipment and simulation systems are tightly integrated with the building, for maximum thermal efficiency.

Fig. 1 shows a cutaway view of the integrated chamber-building system with the largest aircraft in place, the CN-235.

3.2 Heating, Cooling, Humidity and Pressure Control System

The highly integrated heating, cooling, humidity and pressure control system required the most value engineering. To begin with, aircraft heat loads, e.g. from deadweight, portable power supplies, radiated power, etc. were not well known.

A minimal margin on cooling capacity was allowed at minimum temperature to keep the capital and operating cost reasonable. This required attention to interface joints, e.g. with doors and windows, plus a tradeoff between chamber wall thermal cost and cooling system cost.

Ventilation of the chamber was biased towards the high temperature condition where aircraft fuel spills have the most volatility.

Small restrictions in terms of chamber operation in summer and winter ambient temperature and humidity extreme conditions resulted in significant capital and operational cost savings.

An integrated system approach was adopted for the heating and cooling system components:

- Common refrigeration machine for the primary coolants of the chamber climate control and the jet engine air makeup system
- Secondary coolant storage system dedicated for jet engine air makeup system
- Operating cost was minimized by efficient use of equipment, e.g. operate only when necessary

3.3 Simulation System Modularity

All simulation systems were designed to be modular and do not have to be permanently located in the chamber. The benefits of this are:

- Easily reconfigured, expanded, or upgraded
- Minimize the number of penetrations through, or attachments to, the thermal walls

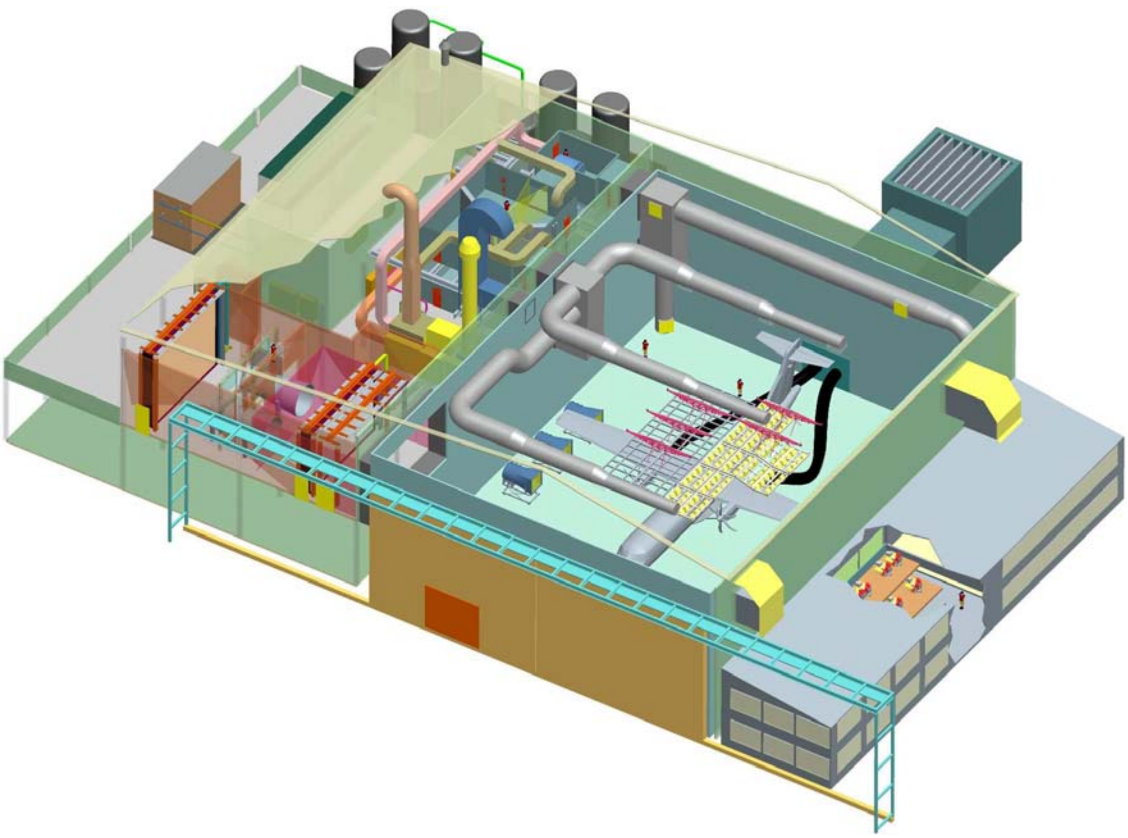

Fig. 1 Schematic of ETF with CN-235 aircraft in place

4. System Features

4.1 Chamber

4.1.1 Thermal Walls

The inside dimensions of the chamber thermal walls are L42m x W32m x H15m. These walls provide a thermal and vapour barrier using proven interlocking thermal panels with R40 insulation rating. Stainless steel was selected for the inside surface material to provide good corrosion resistance. Special attention was paid to sealing all penetrations, in order to prevent unwanted ingress of ambient moisture in sub-zero test conditions.

The enclosing building was designed to react various loads, including: ±500Pa pressure load to accommodate turbojet engine transients, thermal expansion due to the wide internal temperature range, and wind loads on the main vehicle door when open.

4.1.2 Doors, Windows and Vents

The main vehicle door is a two-piece, full height structure that forms one wall of the chamber. The by-parting door, shown in Fig. 2, opens fully within 10 minutes, which is sufficiently fast to get a fire truck or rescue equipment inside quickly. The vehicle door has the same thermal and vapour barrier as with thermal walls, plus inflatable seal with heat tracing.

Fig. 2 External view of ETF showing main vehicle door in closed position

Other doors include personnel access doors with airlocks for ease of entry during climate extremes, and a fire-rated equipment access door connecting the chamber to the equipment storage room.

The number of windows was minimized, in the interest of thermal efficiency and only located at the control room interface. Good visibility of the chamber internals is provided by two 4m x 1.5m windows which are of a heated, 4-pane construction, and include a fire rated shutter system.

Independent positive and negative vent sets are included to prevent severe over-pressure or under-pressure on the chamber thermal wall structure during jet engine transients. Openings are sized to pass the maximum jet engine induced mass flow of 225 kg/sec. These vents provide a thermal and humidity barrier in the normal (closed) position.

4.1.3 Equipment Support System

This system, which is permanently located inside the chamber, is used for rigging and hoisting either the solar simulation panels or the rain simulation system panels above a test object.

The major components are: an overhead monorail system, trolley chain hoists, festoon system for power cables, aluminum strongback frames to span the distance between monorails, and chain slings to attach the solar or rain panels.

Set-up sequence is as follows: panels are brought in by fork lift truck, pinned together in the desired configuration, then cables and/or water pipes are attached, and finally the entire assembly is raised to the desired height.

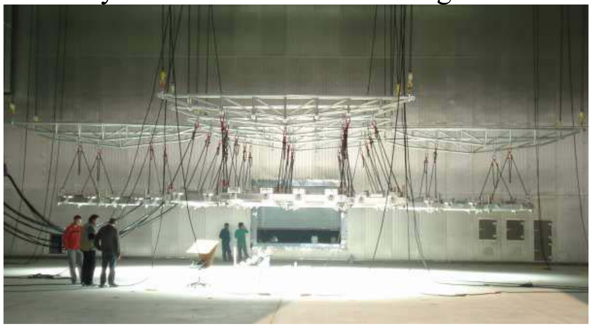

Fig. 3 Equipment support system with solar simulation system installed

4.1.4 Jet Engine Exhaust System

Exhaust from an aircraft engine is collected and ducted outside the chamber through one or more augmentor tubes. The initial installation, intended for turbojet application, includes a single collector and duct large enough to accommodate engine flow plus entrained flow from the chamber. The turbojet exhaust system can be reconfigured to accommodate different engine size and mass flow rates, and is adjustable in height and angle relative to the chamber floor.

Fig. 4 Interior view of ETF showing jet engine exhaust system

4.2 Climate Control System

4.2.1 Cooling and Heating System

This subsystem of the climate control system heats or cools the chamber air, the facility make-up air, and the jet engine make-up air. It also provides the first stage of dehumidification for the facility make-up air and provides cooling of the water for snow simulation.

A two-stage concept is used for cooling: the primary refrigeration loop cools a secondary brine loop which circulates fluid through a heat exchanger in the chamber air handling unit:

- The refrigeration loop includes a high stage compressor system for cooling brine which provides air temperature down to -18°C, and two booster compressors for cooling brine which provides air temperatures -18°C to -54°C
- Large brine storage tanks provide the cooling energy for jet make-up air heating or cooling down to -18°C.

Heating of air up to +54°C is done in a single stage using immersion brine heaters in the facility air handling unit.

4.2.2 Facility and Jet Engine Make-Up Air

The facility make-up air unit (FMAU) has three roles in chamber operation:

- Maintains a positive pressure (125 Pa) in the chamber to prevent ingress of unprocessed ambient air, the biggest potential problem of which is internal ice buildup
- Provides 1.2 chamber air changes per hour using conditioned fresh air
- Dries the chamber air

The FMAU utilizes a cooling coil and a desiccant wheel in an air duct to remove humidity. Humidity can be added up to 100% RH using a boiler and a steam grid system which injects steam into an air handling duct. The humidity control system was designed to economize on drying and steam requirements.

The jet engine make-up air unit (JMAU) cools or heats the test air for jet engine operation. It also reduces the test air humidity to approximately saturated conditions.

The maximum JMAU air mass flow rate is 225kg/sec, sufficient for one turbojet engine operating at MIL power with augmentation ratio of about 1.8. The stored brine tanks enable the JMAU to operate at max air flow for 30 minutes once every 24 hours.

4.3 Simulation Systems

4.3.1 Solar Simulation System

Incident solar radiation can be created overhead of a test object using the solar simulation system. A full spectrum intensity of 1120W/m^2 can be achieved over a 90m^2 reconfigurable footprint with a uniformity of ±50W/m^2. The adjustment of the irradiated footprint is achieved by connecting identical 2.93m x 1.4m footprint panels.

Fig. 4 Solar simulation system

4.3.2 Rain Simulation System

Rainfall rates from 1 to 610mm/hour can be achieved using up to 24litre/sec water input. Virtually any rainfall rate in the range is achieved by variable pressure and using one of five nozzle sizes. The rainfall footprint is adjustable up to a maximum area of 140m^2 by connecting identical 2.74m x 2.74m panels

Fig. 5 Rain simulation system in operation

4.3.3 Snow Simulation System

Snowfall accumulation rates up to 75mm/hour, assuming a snow density of 630kg/m^3, are attained using two snow cannons fed by 2°C water at 0.5litre/sec. The target footprint of 38m^2 and accumulation rate can be achieved by changing the angle of the snow cannons. Fig.6 shows the snow cannons in operation.

Fig. 6 Snow simulation cannons in operation

4.3.4 Wind Simulation System

Ground winds up to 18m/sec can be simulated over a reconfigurable footprint 9.3m^2 using three identical wind machines. The wind machines are supported on scissor-lift platforms, as shown in Fig. 7, to provide a fan centerline height adjustment of 1.6 - 3.2m from the chamber floor level.

Each wind machine fan is powered by a 50hp motor, and includes a honeycomb flow straightener. The operating temperature range for these machines is -15 to +54°C.

Fig. 7 Wind machine

4.4 Control and Data Acquisition Systems

4.4.1 Facility Control

Process and simulation system control is coordinated by a facility control system (FCS) that has the following functions:

- Automatic or manual control of the process loops
- Safety interlocks and coordinated sequence controls
- Supervisory control of all equipment and subsystem operations
- Coordination of facility operations and data collection.

The FCS is an integrated system with a control station in the control room that provides complete control and monitoring of chamber operations. A typical screen capture showing the brine storage tank system at -10°C is given in Fig. 8 below:

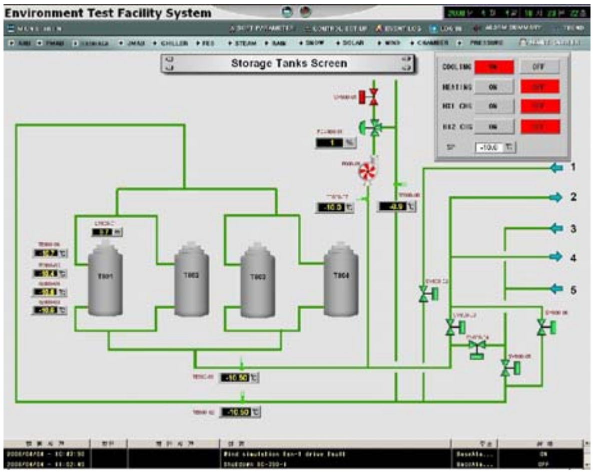

Fig. 8 Typical FCS screen capture

In addition, stand-alone functionality is provided as part of the major subsystems, including:

- Solar simulation system
- Aircraft data acquisition system
- Individual proprietary equipment supplied by specialty suppliers, e.g. variable speed drives.

4.4.2 Aircraft Data Acquisition

Climatic tests of large vehicles typically require hundreds of data channels to monitor the environmental impact of the climate changes on the multiple systems of the test vehicle during hot/cold soaks, engine starts, vehicle systems responses and other transient climates.

Within the budget constraints of this offset project, Boeing provided an initial minimum channel count data acquisition system suitable for initial test projects and which can be expanded to increase data acquisition capability with additional modules as future needs mature beyond the initial facility.

The data acquisition system consists of a data acquisition computer (DAC), a data logger, data acquisition and reduction software and interconnecting hardware and software to receive chamber process data the FCS. The data logger can acquire up to 30 channels of thermocouple or low level voltages up to 100 VDC at rates up to 10 times per second. A schematic of the hardware interconnections is seen in Figure 9.

Boeing provided software and training for Multi Source Data Acquisition Tool (MSDACT), a data acquisition edition written in National Instruments graphical based programming language LabView. MSDACT is primarily used as a software tool to develop distributed data acquisition systems and is specifically tailored to link multiple instruments, shared or test specific, with a variety of tests or users.

The DAC is capable of accepting chamber process data such as pressure, temperature and humidity via a TCP/IP EtherNet connection to the FCS, as seen in Fig. 9 below:

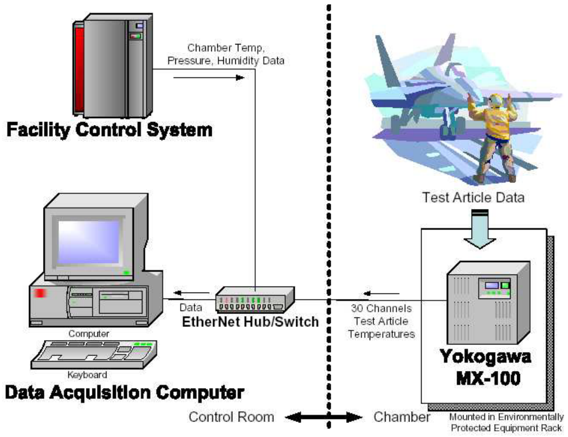

Fig. 9 FCS –DAC interface

4.5 Building Systems

4.5.1 Building Layout and Structure

The enclosing (parent) building incorporates a steel structure designed to withstand the loading imposed by the chamber and local environment such as wind and snow loading. This steel framework reacts loads imposed by the chamber:

- Chamber thermal wall loads: deadweight, internal pressure and thermal expansion
- Equipment support system and solar simulation or rain simulation weight
- Air handling ductwork
- Main door loads: deadweight, internal pressure load and inflatable seal load

There is a firewall in the interstitial area between the steel support framework and the enclosing building. Solar heating loads have minimum impact on the cooling system loads due to insulated external cladding on the building walls and roof.

A control room interfaces to the chamber via a pair of thermally insulated windows. These windows, together with the FCS and DAC hardware being located in this room, give test engineers and facility operating staff good real time monitoring capability of tests in progress in a comfortable thermal and acoustic environment.

Fig. 10 View from control room

One side of the building is a two-floor plant and equipment room area where all the process equipment, such as cooling and heating system, FMAU, JMAU, etc, are located. The first floor of this area contains two electrical rooms to accommodate the high electrical power required to operate the process system.

A silencer is included to attenuate the high noise level emanating from the jet engine exhaust system in the chamber. A roll-up thermal door is used to minimize the heat loss (or gain) to the chamber when the jet engine is not operating. The noise level measured 76m away from the silencer during F-16 engine operation was below 70dB which is well within the design requirements of 80dB. With the silencer, the ETF is arguably the world's first climatic hush house.

4.5.2 Building and Chamber Thermal Floor

The parent building floor also incorporates the chamber floor specially designed to endure 70,000kg of static load and 40,000kg of dynamic load such as jet engine thrust, in addition to acting as a thermal and moisture barrier. This floor consists of two layers of 30cm thick steel reinforced concrete with a 30cm thick Styrofoam layer in between.

The floor has many aircraft tie-down points including one main hook which can withhold 40,000kg force of thrust. All these tie downs are specially designed and constructed to accommodate large thermal mismatch during large temperature changes in the chamber.

The steel reinforced floor can be seen in a construction photo shown in Fig. 11.

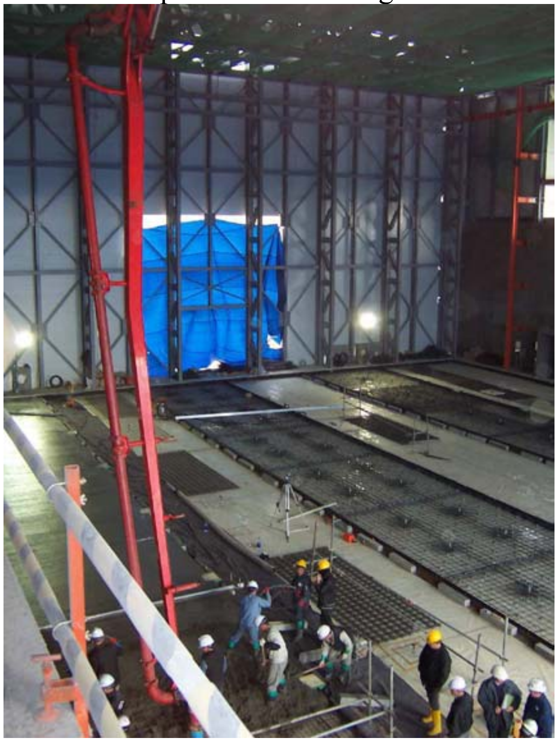

Fig. 11 Construction photo showing wall support structure and steel reinforced concrete floor

The large amounts of water produced during rain, snow and high humidity tests are collected in a drain in the chamber floor and then processed by a remote air sealed drainage and catchment system. An XIT type 1-ohm grounding strip is also imbedded in the floor.

5 Safety in Design and Operation

Special attention was paid to safety in design of the ETF:

- Pressure relief vents for jet engine transients
- Fast opening Main Doors for Fire/ Rescue Equipment ingress
- Fire wall between thermal walls and building
- Fire protection, warning beacons
- Fire rated shutters on outside of observation window and equipment door

In addition, an interlock system is an integral part of a operational procedures:

- Use of controlled key interlocks
- Close coordination with pilot of aircraft during engine run-up to minimize chance of any external air entering the chamber

6 Initial Operational Results

At the time of writing, the ETF is undergoing shakedown tests and initial acceptance testing. Some very encouraging initial results are given below.

6.1 Temperature and Humidity Control

Initial results show chamber temperature regulation to be well within the requirement of ±2.7°C. The screen capture shown in Fig. 12 illustrates the FMAU temperature regulation as required to maintain chamber temperature

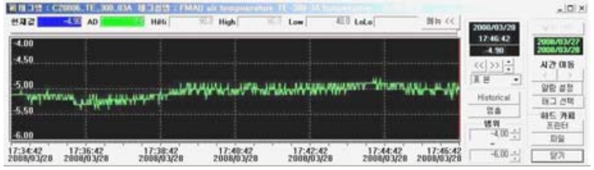

Fig. 12 FMAU air temperature regulation at -5°C

The screen capture in Fig. 13 below shows a chamber air temperature ramp up to, and then maintaining, a set point of 20°C.

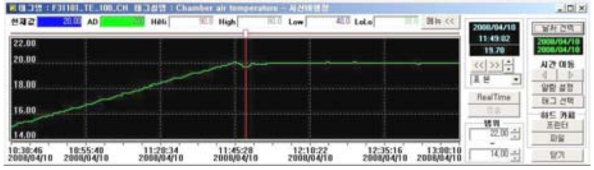

Fig. 13 Chamber air temperature ramp and steady state

Humidity control has proven to be excellent. Fig. 14 below gives a measure of both humidity uniformity, as indicated by the difference between the maximum and minimum RH values among an array of 20 sensors, and the variation of this difference over time.

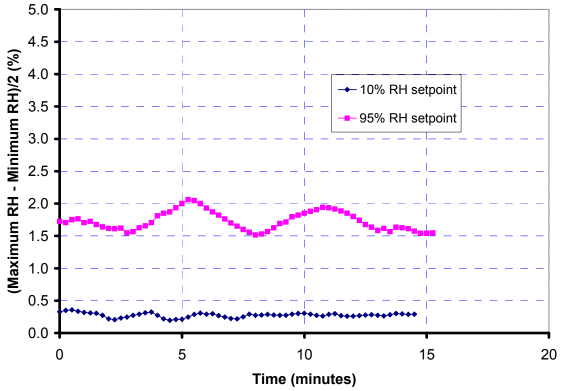

Fig. 14 Humidity uniformity and regulation (20°C)

This result shows uniformity and regulation to be well within the specified tolerance of ±5%RH.

6.2 Solar Simulation Control

Fig 15 shows a typical contour plot for the incident radiation measured (empty chamber) on a horizontal plane 2.3m below the lamp array – a location typical for most aircraft. The panel module arrangement is the same as that shown in Fig. 4. Each color represents a 100W/m^2 increment, with the maximum level being 1100-1200W/m^2. The uniformity over the target area of 93m^2 was found to be well within the requirement of ±50W/m^2.

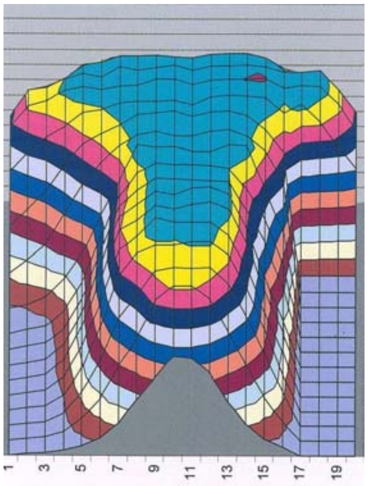

Fig. 15 Solar simulation system radiation contour plot

7 Provision for Future Upgrades

The ETF design includes provision for JMAU upgrade, specifically reduction in minimum air temperature to -54°C, to match the minimum chamber temperature level:

- Equipment layout to allow additional refrigeration high stage and booster compressor system
- Independent brine loop with dedicated heat exchanger to reduce the make-up air temperature from -18°C to -54°C.

At the time of writing the design work for this upgrade is well underway.

Solar simulation and rain simulation system designs include an expandable footprint capability. Specifically, the equipment support system coverage is already in place, as is utility supply system.

8 Concluding Remarks

A cost-effective environmental test facility has been recently designed and constructed at the ADD aircraft development test center in Korea to enable validation of prototype vehicle operation under extreme climatic conditions. Initial shakedown and commissioning results have demonstrated excellent regulation and uniformity of primary climate parameters. Provision for growth has been provided for simulation systems and jet engine makeup air.

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