THE INSTITUTE OF REFRIGERATION

Measurement of Air Flow in Transport Refrigeration Units

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Introduction

Evaporator airflow, or the volume of temperature controlled air delivered from the evaporator is the final medium which maintains perishable cargoes at their correct temperature. Fans, be they centrifugal, axial, mixed flow or propellor will when driven, usually by an electric motor, deliver a volume of air according to their design. When fans are installed in refrigeration plant a certain amount of resistance is imposed on the fan, pushing its working point back up the fan characteristic (see Fig. 1) with a corresponding reduction in volume. Resistance takes shape in the form of evaporators and heat exchangers, ductwork, expansion chambers, contractions, elbows, pipes and paraphernalia which may partially block the flow.

In this paper, pressures are quoted in mm standard water gauge, fan power-draw in watts, and volume in m^3/hour. However in the world of Shipping Refrigerated Cargo volumes are frequently described as air changes/hour. An air change per hour is that volume which will completely change all the air in a cargo hold or a Marine Freight Container or a Refrigerated Semitrailer in an hour. Thus a transport unit having a volume of 28.3 m^3 (1000 ft3) will experience 60 air changes per hour, when subject to a volume of 1700 m^3/hour(1000 ft^3/min.)

Measurement of fan volume on board ship was one of the many tasks undertaken by the Predecessor of SRCRA the Refrigerated Cargo Research Council. SRCRA was formed by its members in 1961. In those early days at SRCRA, members frequently required measurements of air volumes delivered to holds and lockers in their refrigerated cargo ships. A suitable flow area was selected and measured in order to determine its area. This flow area was traversed with an anemometer in order to obtain the average flow velocity. A corrected average flow velocity and hence the volume airflow can be calculated. Additionally to provide a complete picture of air delivery off the coolers, static pressure drops across the cooler and ductwork, fan motor volts, amps, watts and r.p.m. were also measured if possible.

The results of testing would then be compared with the Evaporator Fan Manufacturer's fan characteristics to establish the state of art regarding the equipment's performance. Static pressures were measured using an inclined manometer, and it was often very difficult to obtain true static pressures. On board ship duct cross-section areas were large and with hold air-change rates of the order of 35-40 changes per hour, local air velocities were modest giving rise to minute dynamic heads. Measurements were usually taken in a great rush, often with dock-workers or ship's crew breathing down your neck. The log Tchebycheff rule for velocity traverse as outlined in BS 848 (Ref 1) was not used and results to within ± 10% were considered acceptable.

Over the last two decades, everything has changed.

In Transport Refrigeration today, the volume of air delivered by the evaporator fan is considered of equal importance as the net refrigeration capacity. Consequently there is much pressure from both operators and manufacturers on organisations such as SRCRA to improve the accuracy of measurement of all parameters associated with evaporator fan performance. This paper discusses problems encountered, describes and compares current methods of measurement and goes on to suggest the establishment of a specific standard to be used to measure the evaporator fan airflow characteristics. Ideally the standard would cover all Transport Refrigeration systems, be they ships, marine freight containers, clip-on-units or road-transport vehicles. The Paper ends with a section covering the measurement of the performance of fan ventilated marine freight containers. This particular unit of trans-

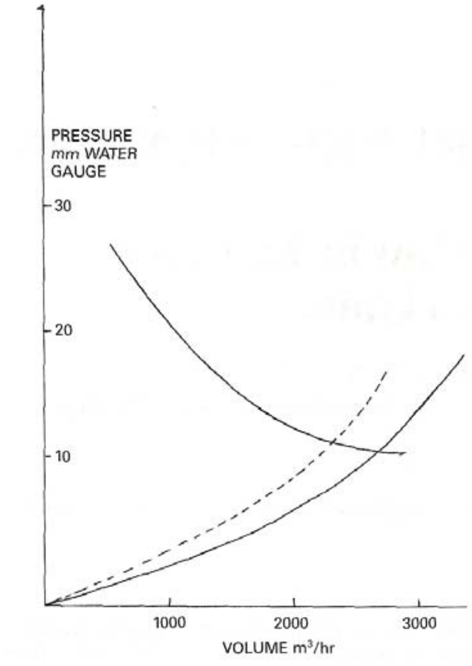

Fig. 1. *Typical single speed system resistance/fan characteristic graph.*

port equipment, though not refrigerated, is used to ship commodities such as onions world-wide and therefore any refrigerated transport airflow measurement standard· to be considered, ought to cover ventilated containers.

The early days of Containerised Marine Transport

The appearance of Marine Freight Containers in 1969 in the Europe/Australia Trade heralded new concepts. A fundamental feature in the design of the insulated containers to be used in this trade was the movement of cooling air in and around and out of these transport units. At last it was possible to assess performance of equipment under laboratory/test chamber conditions as containers, being totally inter-modal, can readily be delivered anywhere.

Porthole Insulated Containers were the first type to be used in the Australia Trades. On board ship, cold air was delivered to the ship-load of 1000 plus containers by ductwork, with specially designed couplings being used as the final connection to each individual container. This new generation of ships, known as container-ships, still retained a centralised refrigeration plant, complete with a secondary refrigeration system, which reflected the best marine design at the time. Some of the later Container Ships designed to carry porthole containers use a system known in the trade as the "Con-Air System". This system is based on separate ductwork modules for each bay in the ship, with each module having its own direct expansion plant.

At SRCRA a porthole container pressure/volume test rig was constructed. The rig was based on BS 1042 (Ref. 2) with an orifice plate being used as the pressure differential device to measure volume. Many varieties of porthole insulated containers were thoroughly tested to determine pressure/volume relationships. 60 air changes was the design criteria, at a pressure drop of no more than 25 mm Standard Water Gauge, though most of the delivery on board ship was around 40 air changes. All these containers were 20 ft x 8 ft x 8 ft. ISO standard (Ref. 3) having an internal volume of approximately 27 m^3. Flow volumes of 1700 m^3/hour passing through 254 mm diameter portholes and the delivery and return plenum chambers produce dynamic heads resulting in typical pressure drops of 19 mm Standard water gauge.

In order to provide temperature control for insulated porthole containers when not connected to refrigeration either on board ship or at a container terminal, Clip on Refrigeration Units were introduced. These units are direct expansion plant mounted in a steel frame, which clips on to the porthole or front bulkhead end of the container. Return air from the top porthole of the container is sucked into the adjacent porthole of the clip on unit by the evaporator fan. This air is then blown over the evaporator and returned to the lower (delivery) porthole for circulation within the container.

Early Clip-on-units were designed to operate at 60 air changes and were fitted with single speed evaporator fans. When coupled to a container, evaporator fan volumes were measured with an anemometer in the same method as on board ship measurements. The BS 1042 rig was used to measure the pressure/volume characteristic of the Clip-on-unit evaporator fan.

Experimental work had shown that most commodities were safe for short periods without refrigeration, relying on the insulating properties of the container alone. Initially there was a limited demand for Clip on units, as many final deliveries of perishable commodities from refrigerated container ship/port terminal refrigeration plant were accomplished without refrigeration.

The new equipment met its specifications, and with great confidence, it entered service, successfully carrying frozen food-stuffs and fruit in the Australia Trade.

The North Atlantic

In the early sixties, the first family of modem intermodal freight containers went into service in the North Atlantic Trade. These units were built prior to the establishment of ISO and were therefore built to a size which suited individual shipping requirements. For example, Sea Land, a well known company in the North Atlantic at that time used containers of 35 ft. length. The insulated versions of this container type were fitted with their own transport refrigeration unit. These units were marine versions of plant originally developed for use in insulated vans and semi-trailers (i.e. road vehicles). The design of this plant included an evaporator, which slotted through the top of the front bulkhead. The evaporator fan blew air through the evaporator across the top of the cargo, the air then returning via gaps in the stow to the suction side of the fan. It was unusual to fit an evaporator bulkhead at that time, indeed the evaporator intruded significantly into the cargo space. The operational flexibilities of this type of refrigerated container quickly became obvious as it could be carried on the deck of any ship, providing power was available to drive the refrigeration system.

Early Integral Reefers

Regrettably SRCRA never tested any of those early North Atlantic Containers. It soon became obvious to Operators in the Europe/Australia trades that there was a requirement for more flexibility in equipment than was available from the porthole system. In those days porthole containers were not operated above deck as they are today, in conjunction with clip-on units, and so the 20 ft x 8 ft x 8 ft integral reefer container appeared on the scene. These containers were built to ISO dimensions and take their name from their dedicated refrigeration units, which were integral within the 20 ft length. In order to maximise carrying capacity, the space provided to house the plant has to be as small as possible. In those days matters were arranged so that the front or bulkhead end was divided down the middle. One half was used to house the compressor and condensing section, while the other accommodated the evaporator.

The drawback of this design soon became apparent, though not before a number had been delivered for service. Having an evaporator and fan on one side only, resulted in an asymmetric airflow pattern in the delivery to the reefer floor section. No matter what was changed in the delivery area, by way of extra ducts and baffles, significant improvements. in the airflow pattern never materialised.

Integral containers quickly established themselves in many trades. Their versatility in that they can be carried on the deck of any ship, provided suitable electrical supplies and lashing points are available, gave shippers a very useful alternative type of refrigerated container. Early Integrals were fitted with water-cooled condenser facilities on an either/or basis with the air condenser, so that they could be used below deck without fear of a build up of the heat rejected by air condensers causing very high condensing temperatures. In recent years the water cooled condenser facility has lost favour, the equipment now being operated below deck, with the installation of 1.
suitable extra fans and ductwork to remove the air-cooled condenser heat.

The first movement away from original ideas

Containerisation of the South African Fruit Trades in the 1975/78 period generated considerable work with a view to improving the pressure/volume relationship of Porthole Containers. For South Africa the container height was increased to 8 ft 6 ins., and all insulated units had to have an internal length of at least 5.8 m to accommodate a pallet containing a broken-down Volkswagen car which were shipped out on the south-bound leg. To achieve this condition the delivery and return plenum chambers used in the porthole design were reduced in width to no more than 75 mm. Narrowing the plenum chamber widths down from 125 mm throttled the airflow and increased the dynamic head loss. Improved plenum chamber design, such as radiused inside edges to the portholes and removal of most sharp edges, compensated the increase in pressure drop (Ref. 4). Interest in Clip-on refrigeration units for these new porthole containers was limited.

There was a steady demand for new Integrals, and once the early design faults were rectified a number of these containers were sent for test at SRCRA over the 1978/85 period. Evaporator fans were single speed operating at about 70/80 air changes were of the shrouded propellor type. By this time the general layout of the main components of the refrigeration plant had changed, allowing evaporator air to be delivered equally to both sides of the container.

To produce evaporator fan performance curves for this family of Integral Reefers, a test rig (see Fig. 2) was developed which enabled the system resistance to be measured together with the fan pressure/volume characteristic. The rig was a compromise in that it followed BS 848, except that the large upstream suction chamber was replaced by a smaller chamber which fits exactly the return air slot to the evaporator and that pressure drop across the evaporator section was measured instead of upstream suction chamber pressure.

The system resistance is measured by blowing varying volumes around the container using external booster fans. Each volume is measured using the calibrated orifice plate, while the positive static pressure difference between air return and air delivery gives the system resistance at that volume. With the evaporator fan operating, volumes are again measured using the calibrated orifice plate. The negative static pressure difference between the air return and air delivery is again noted. The booster fans are operated together with the evaporator fan. Under these conditions a series of air volumes are blown round the system. With increase in volume the negative static pressure difference reduces, eventually reaching zero and finally becoming positive when the air flow volume from the booster fans overcomes the upstream static pressure. The rig was used extensively producing requisite graphs of pressure and power-draw against volume.

Current designs and their testing

Around 1985/86 a number of changes occurred.
New Zealand started to export chilled Cryo-vac packed lamb to Europe. Temperature control requirements for such shipping were very exacting, and to ensure suc-

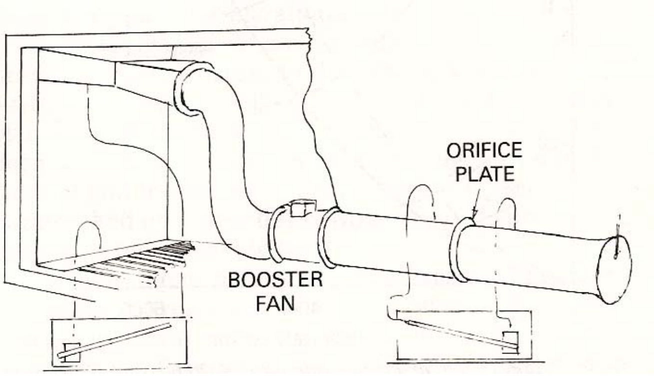

Fig. 2. SRCRA booster fan rig for measuring evaporator fan volumes.

cessful outturns, Container Operators decided to re-equip with Integrals and Clip-on Units that were capable of 120 air changes per hour. Evaporator fans would be 2-speed, so that carriage at - 20°C or lower would be at low fan speed condition to maintain net refrigeration capacity, ~hat would otherwise be severely penalised by the huge quantity of fan heat appropriate to the high speed operation. Fig. 3 shows the evaporator fan pressure/volume/power draw relationship for a typical 20 ft integral refrigerated container at that time. Alongside these high evaporator fan volume 20 ft reefers, remained sustained interest in 40 ft units, albeit with relatively modest fan volumes. Fig. 4 shows the evaporator fan performance for a typical example of the 40 ft Integral Reefer. These graphs are all produced from the data obtained using the SRCRA rig.

The changes in trading patterns has led to the increased use of Clip-on units/porthole containers. Such combinations are frequently carried on deck and regulations are now in force prohibiting any storage or shipment of frozen foodstuffs without refrigeration. Suddenly there was a demand for Clip on units in greater numbers and coupled with the need to replace early models, dormant interest in clip on units revived.

SRCRA built an experimental Clip-on unit (evaporator section only) to investigate- the problems associated with 120 air changes. The rig consisted of scrap clip-on frame to which was bolted an evaporator, ductwork and a 2-stage axial flow fan. The largest diameter 390mm axial fan arrangement would when coupled to a porthole container just produce a volume equivalent to 120 air changes per hour. The penalties for this volume was a pressure drop of 100 mm. Standard Water Gauge and a power draw of 2.7 kW. These figures took a little digesting, as up to this point in time typical pressure drops and power-draws were of the order of 35-45 mm. Standard water gauge and 0.81.0 kw. Results of pressure/volume testing this rig are shown in Fig. 5, which also shows the effects on one fan only in operation. Further tests were conducted using a 2-stage 305 mm dia. axial fan. Though obviously more attractive in terms of space and power draw, this arrangement did not meet 120 air changes per hour.

Manufacturers of Clip-on refrigeration units fitted centrifugal fans instead of the shrouded axial type. Centrifugal fans, particularly those with backward curved vanes can be designed to meet the 120 air change requirement when operating in the high speed 60 hz mode, with a lower power-draw than the 2-stage axial fan used in the SRCRA rig. Indeed if the eye of the centrifugal fan is positioned in line with the return air porthole, the fan's centrifugal action turns the air through 90° thus reducing the system resistance by approximately one dynamic head. The performance of the centrifugal fan at low speed did not meet specifications so readily. A typical example of the recent generation of clip on units evaporator fan performance is shown in Fig. 6.

Pressure/volume testing these units fitted with centrifugal farts proved difficult. Specified evaporator fan volumes had now become a matter of contractual importance and much interest was centred on the results. As such several Integral and Clip-on refrigeration units were tested using the SRCRA developed method, the Log Tchebychev method as outlined in BS 848, and one of the BS 848 boost fan methods precisely as described. Figs. 7 and 8 show the later two rigs, while tables 1 and 2 compares the results of testing from all three methods.

These tables illustrate the degree of variation in airflow test results. It would be useful to be able to declare

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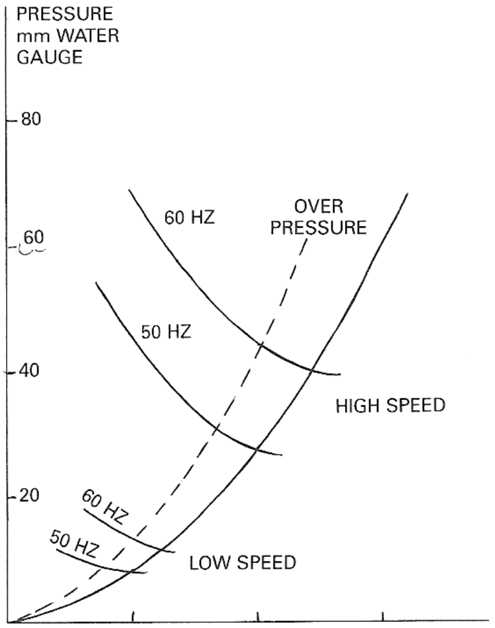
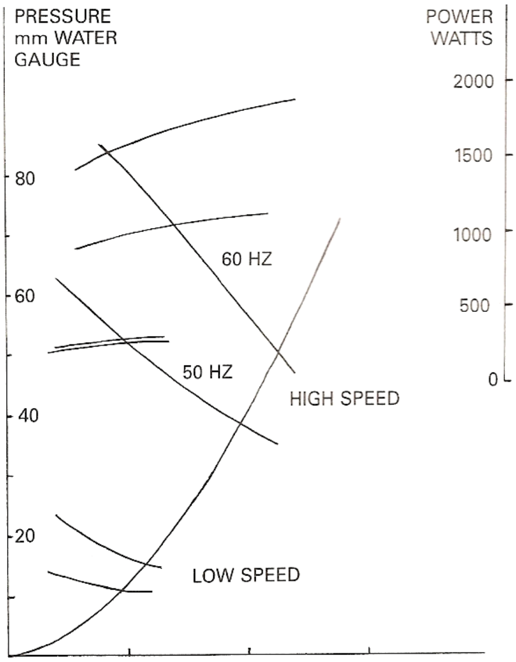


Typical high air-change rate integral 20 ft reefer multi speed evaporator fan characteristics. .



Typical 40 ft Integral reefer evaporator fan characteristics

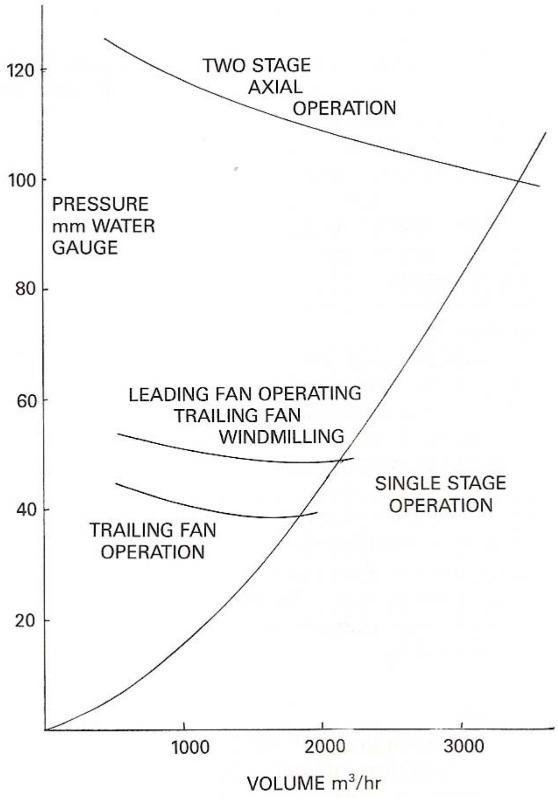


Fig. 5. SRCRA experimental 2-stage axial evaporator fan clip-on unit performance.

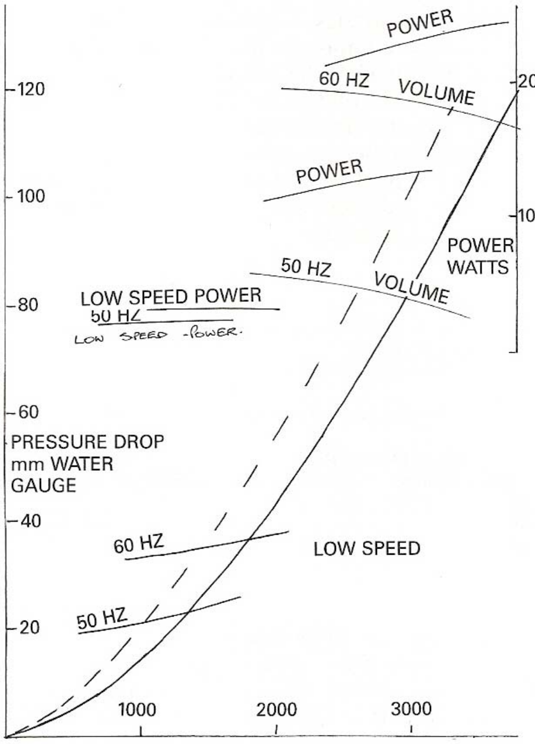


Fig. 6. Typical evaporator fan performance curves for a 120 air change clip on unit.

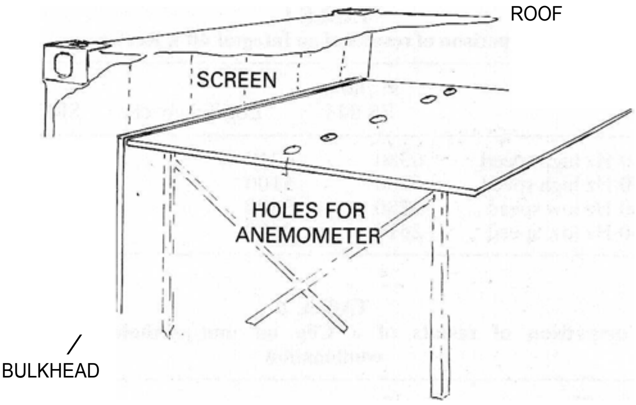


Fig. 7. Drawing of the rig used at SRCRA to measure evaporator fan performance using the Log Tchebychev Method.

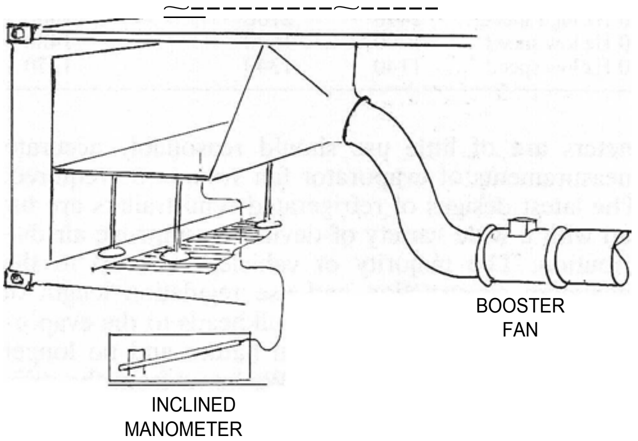


Fig. 8. Booster fan rig to BS 848.

that the three methods employed give the same answers. However it is obvious that such a deduction is not possible.

Testing Integral reefers at SRCRA over the last five years shows that there is good agreement between evaporator fan volume results whatever method used. The SRCRA compromise method gives a lower system resistance for a given volume due to the elimination of the "weir effect" on air passing over the return air slot. Testing Clip on units over the same period shows that there is good agreement between both boost fan methods but that the Log Tchebychev method reverted to the accuracy level associated with more traditional anemometer methods. This is due to the air returning to the central porthole generating incompatible steamline patterns for the Log Tchebychev Rig.

Road Transport Refrigeration Units

In the event the title and summary of this paper has proved to be premature in that SRCRA had hoped to have copious results relating to pressure/volume testing of road transport units. To date only two units have been tested, one was tested using the booster fan method and the second model, fitted with remote evaporator, had its evaporator fan volume measured using the Log Tchebychev Method.

Currently, apart from what individual manufacturers do for themselves, testing of Road Transport Refrigeration refrigeration units is governed by the ATP agreement. Such refrigeration units have their refrigeration extraction rates measured using calorimeters. Calori-

TABLE 1

Comparison of results of an Integral 40 ft Reefer

Free Blow	*M³/ hour*		
	BS 848	Log Tchebychev	SRCRA
60 HJ; high speed	6380	6210	6630
50 Hz high speed	5400	5100	5390
60 Hz low speed	3280	3300	3280
50 Hz low speed	2610	2680	2635

TABLE 2

Comparison of results of a Clip on unitjporthole container combination

Free Blow	*M³/ hour*		
	BS 848	Log Tchebychev	SRCRA
60 Hz high speed	2940	3420	3020
50 Hz high speed	2410	2760	2460
60 Hz low speed	1700	1670	1480
50 Hz low speed	1140	1340	1170

meters are of little use should reasonably accurate measurements of evaporator fan volume be required. The latest designs of refrigerated semi-trailers are fitted with a wide variety of devices to improve air distribution. The majority of vehicles built up to the maximum construction and use regulation length of 13.35 m are now fitted with bulkheads to the evaporator which in turn are slim in nature and no longer intrude into the cargo space. We know from the difficulties that some operators are experiencing that fine temperature control in road vehicles is not easily achieved. Air is the final temperature controlling medium and the time has arrived for the Refrigerated Road Transport Industry to follow its Counterparts in The Marine World who now insist on an accurate assessment of the pressure/volume characteristics of all equipment. The BS 848 rig could be readily adapted to provide such measurements.

Anemometry versus booster fans

On board ship anemometers are still used to measure the mean air velocity at either air return to the cooler or air delivery. Given the choice, the suction side of the fan is best used as the airflow will tend to be streamline. On the delivery side, eddies and turbulence will introduce measurement errors thereby limiting the usefulness of the results. The addition of some simple ducting to either side of the cooler and its fan will improve matters considerably, enabling the test-engineer to measure mean airspeed according to the LogTchebychev rules as described in BS 848. The addition of a duct will slightly increase the static pressure against which the fan operates which means the results based on this method will be slightly lower than the true fan/system working point volume. To my knowledge it has never been possible to introduce air volume measurement ducting on board ship.

Fan Ventilated General Purpose Containers

In around 1981 the first forced ambient air shipment of onions from the Southern Hemisphere to the Northern Hemisphere commenced. It was found that a large market existed for thousands of tonnes of out of season premium Australian and New Zealand onions especially where local stored onions were either exhausted or of poor quality.

Initially the shipments occurred in one trip modified general purpose containers with holes cut in them for ventilation slots and fans.

In 1990 P & 0 Containers introduced a purpose built fan ventilated container with a ventilation slot it its base. It was designed in such a way to be of a standard internal size for shipping car components south bound or onions northbound. When used as; ventilated container a hatch in the door is opened and; single phase electric motor driven 300 mm dia. propeller fan installed.

Fan ventilated container testing is carried out by firs attaching a rig complying to BS 848 as previously described to the ventilation slot and producing a load curve. The rig is then attached to the fan inlet and; performance curve obtained. The intersect point of the two curves is taken as the operating point for the container. An allowance for the onion air resistance can be added to the ventilation slot resistance.

Over the years a container air change rate of about forty has been accepted by industry as the flow rate level, which helps prevent the formation of condensation on the onions.

The Future

For all evaporator fan performance in transport with the exception of ship's holds, the method of measurement of evaporator fan volume should be BS 848 booster fan method. Indeed at SRCRA a new, rig will shortly be constructed which will comply with the American National Standard, ANSI/AMCA Standard 210-85 (Ref. 4). This standard specifies the use of three calibrated nozzles. These nozzles, which vary in throat dia. ensure improved accuracy of measurement across the now much wider range of specified volumes

The increase in volumes and pressures mean that in some instances the limit of our present method of sealing duct and chamber joints has been reached. The new rig will be designed to seal automatically and will be much lighter and therefore more readily installed to test transport equipment.

References

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2. BS 1042 1981 Methods of measurement Fluid Flow in closed conduits.
3. ISO 1496 Specification and Testing of General Purpose Containers.
4. Paper to the Institute of Refrigeration 1980:-Factors affecting the Design of Containers and the carriage of Refrigerated Cargo by G. R. Scrine and C. J. Bowyer.
5. *ANSI/AMCA* 210-85, ANSI/ASHRAE 51-1985 Standard, Laboratory Methods of Testing Fans for Rating.

SRCRA

Membership of Shipowners Refrigerated Cargo Research Association, is open to Shipping Companies who own and operate refrigerated shipping tonnage The Staff at SRCRA's laboratory/Test Station work for the Members either at the Cambridge Laboratory or on Board ship or at Ports or Docks or any other site, as necessary.