# CHAPTER 31

# AIR TRANSPORT



AIR freight service is provided by all-cargo carriers and passenger airlines. The latter companies also have all-cargo aircraft. Wide-body aircraft have a passenger and cargo mix on the main deck, increasing cargo capacity (Figures 1 and 2). All lines maintain regularly scheduled flights so shippers may adequately plan delivery time. Special charter flights are also available from regular terminals and from airports located close to the producing areas. Payload range comparisons of wide-body jets are shown in Figure 2.

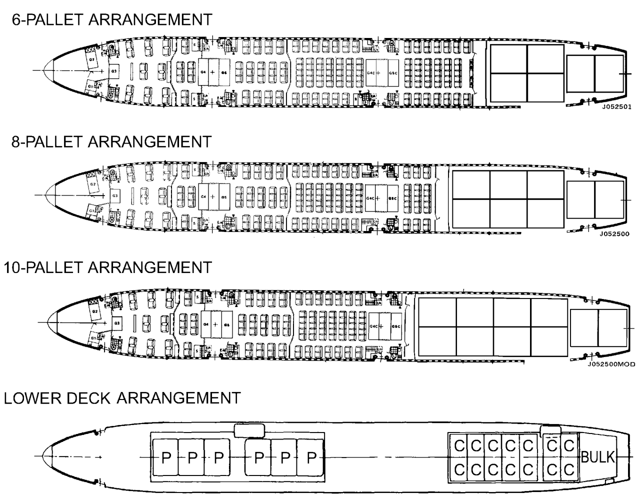


**Fig. 1 Flexible Passenger/Cargo Mix**

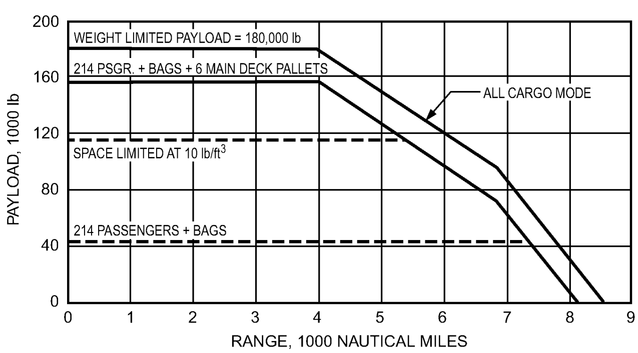


**Fig. 2 Payload-Range Comparison for Wide-Body Jet**

Prospective shippers should contact the airlines serving their locality to obtain specific details for handling perishable shipments.

## PERISHABLE AIR CARGO

Some aircraft have cargo compartment temperature control with setting options ranging from just above freezing to normal room temperature. Most compartments have a single temperature control. The control is achieved by balancing the skin heat loss with the supply of expended passenger cabin air and, when necessary, the introduction of hot jet engine bleed air through eductors. Skin heat exchangers are used to assist in maintaining the lower temperatures at high (cold) altitudes. This mode of refrigeration is not available at low altitudes or on the ground, where skin temperatures can exceed the compartment temperature significantly. Refrigeration techniques for aircraft rely primarily on precooling, insulated containers, dry-ice-charged containers, quick handling, and short-time exposure to adverse conditions. Airports seeking to expand cargo operations are adding refrigerated warehouses internationally. The availability of refrigerated warehouses is generally the result of specific market demands and competition.

Fruits and vegetables, flowers and nursery stock, poultry and baby chicks, hatching eggs, meats, seafoods, dairy products, live animals, whole blood, body organs, and drugs (biologicals) are transported by air. Items so shipped are generally of such a perishable nature that slower modes of transportation result in excessive deterioration in transit, making air movement the only possible means of delivery. Certain early season and specialty fruits and vegetables can be flown to distant markets economically because of the high market prices when there is a short supply. Some items, such as cut flowers and papayas, arrive at distant markets in better condition than they would otherwise, so the extra transportation cost is justified. Flowers are shipped on a regular basis from Hawaii to the mainland United States and from California and Florida to the large midwestern and eastern cities. Air movement of strawberries has increased tremendously, including direct shipments to global destinations. Papayas are shipped from Hawaii almost exclusively by air.

When carefully handled, ice cream is shipped successfully to overseas markets from the United States; however, some unsuccessful shipments have occurred because customs inspectors have opened containers for inspection and have taken too much time. The lowering of trade barriers has reduced the risk.

### Fruits and Vegetables

All fresh fruits, vegetables, and cut flowers are alive and remain living throughout their entire salable period. Being alive, they respond to their environment and have definite limitations regarding the conditions they can tolerate. They remain alive by the process of respiration, which breaks down stored foods into energy, carbon dioxide, and water, with the uptake of atmospheric oxygen. Respiration, together with accompanying chemical changes, results in

The preparation of this chapter is assigned to TC 10.6, Transport Refrigeration.

quality changes and the eventual death of the commodity. These internal changes associated with life cannot be stopped but should be retarded if a high level of quality is to be retained for a prolonged period.

### Seafood

Seafood and fish also benefit from the speed of air freight. The abundance of fresh fish at restaurants and markets throughout the United States is the result of air shipment.

### Animals

Design of aircraft cargo compartments for animals is based on SAE *Standard* AIR 1600 and the U.S. Code of Federal Regulations, Title 9. Temperature and ventilation regulations as well as recommendations for birds and animals of all sizes are included in these documents. Air transportation limits exposure to the extremes that would otherwise require special handling and additional cost for animal safety in accordance with the regulations.

## PERISHABLE COMMODITY REQUIREMENTS

The justification for the air movement of perishable commodities is based on (1) the time element and (2) the delivery of a higher-quality product than is possible by other modes of transportation. Better delivered quality increases returns to the shipper. This not only offsets the added transportation costs but increases consumer demand and acceptance as well. The market quality of perishable items is definitely controlled by a time and temperature relationship. Temperature cannot be ignored even for the few hours now required for transcontinental air movement. Proper temperature and humidity must be maintained at all times.

Pentzer et al. (1958) lists desirable transit environments for most perishable horticultural commodities. Figure 3 shows the result of a test of air shipments of strawberries from California to Chicago in a refrigerated but uninsulated container. The shipments were exposed to high ambient temperatures during ground handling at origin, resulting in fruit temperatures ranging from 50 to 60°F instead of the desired 32 to 34°F. These berries were compared with those shipped by rail in 4.5 days with temperatures averaging 38°F for the transit period. Appearance and decay on delivery were about the same for both lots. Thus, the advantage of the short 22 h air movement was offset by a loss in quality arising from the unfavorable temperature.

Top quality of many of the most perishable commodities can be significantly reduced by only a few hours' exposure to unfavorably high temperatures. Many drugs (biologicals) and other items, such as whole blood, can be rendered completely ineffective or toxic if not kept at the specified low temperature.

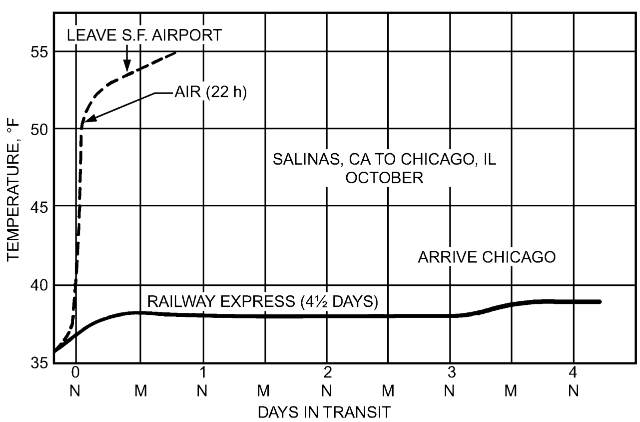


**Fig. 3 Temperature of Strawberries Shipped by Air and Rail**

Some flowers, fruits, and vegetables respond favorably to reduced oxygen levels, increased amounts of carbon dioxide, or both, which could be maintained by gastight packaging or containers.

The maintenance of temperatures near freezing is not desirable for all products because some are subject to chilling injury when they are exposed to temperatures well above the freezing point. Chilling injury is most pronounced in tropical products, such as bananas, tomatoes, cucumbers, avocados, and orchids. Temperatures above 55°F are usually safe for cold-sensitive commodities. Other items, such as cut flowers, require temperatures between 32 and 55°F.

Certain fruits and vegetables require humidity control. Humidity should be kept between 85 and 95% to prevent wilting and general loss of water. The relative humidity in the cabin of an airplane flying at about 40,000 ft is generally less than 10%. However, the respiration of fruits and vegetables, placed in closed containers with recirculated cooling air, should produce the required humidity level with no additional water added.

Certain vegetables, such as peas, broccoli, lettuce, and sweet corn, have high respiration rates and the heat produced may amount to the equivalent of 250 lb or more of ice meltage per ton of vegetables per day at 60°F. In designing the refrigeration systems for aircraft containers, the additional evaporator capacity required to handle the heat of respiration should be considered.

## DESIGN CONSIDERATIONS

A refrigeration or air-conditioning system for a cargo airplane or airborne cargo containers has conflicting design temperature requirements, depending on the type of cargo to be carried, which makes it difficult to use one optimum refrigeration system for all kinds of cargo. For example, frozen foods should have a temperature of 0°F or lower, fresh meat and produce 30 to 45°F, and live animals generally require temperatures in the same comfort range as for humans. Today, many of the commercial jet cargo planes operate with the main cabin divided between cargo compartments and passenger compartments, and they are supplied by a single air system controlled to the comfort of the human occupants. In this case, perishable cargo must be packed in containers, insulated, and iced or precooled.

The design ambient temperatures that an airplane will experience in flight are given in Chapter 10 of the *ASHRAE Handbook—HVAC Applications*. A cargo jet cruising close to Mach 0.9 has an increase in skin temperature over ambient of about 50°F. With an all-cargo load, the basic air-conditioning systems are capable of maintaining main cargo compartment temperatures on a design hot day from 40°F at 30,000 ft to 30°F at 40,000 ft.

The air-conditioning systems are equipped with controls to prevent freezing of moisture condensed from the air at low altitudes. With the extremely dry air prevailing at cruise altitudes, an override of these anti-icing controls would permit an even lower cabin temperature, although it is doubtful that storage temperatures of frozen goods could be met. Thus, some insulation would still be required in frozen food containers. Further, the airplanes are often required to hold at relatively low altitudes of 20,000 ft or less (because of heavy traffic at the busier airports) for periods of 30 min or more.

Permanent attachment of a mechanical refrigeration system to a cargo container may not be desirable for several reasons: increased load, reduction in usable volume, and difficulty in rejecting the condensing unit heat load overboard. These objections are particularly applicable to containers carried in the main cargo hold. On the other hand, permanently attached units would permit refrigeration of just part of the cargo load while the remainder could be held at temperatures in the normal human or animal comfort zone. Temperature control of products requiring widely differing transit and storage temperatures would be more feasible with onboard refrigeration units.

## SHIPPING CONTAINERS

Fruits and vegetables are generally shipped in the same containers used for surface transportation: wooden boxes, veneer crates of various types, or fiberboard cartons. Most flower containers are constructed of either plain or corrugated fiberboard materials. Wooden cleats are used for bracing material, generally as dividers or corner braces inside the cargo box. Where lading may be exposed to very cold surfaces, external cleats may be used as spacers to prevent direct contact. Certain flowers such as gardenias and orchids may be packaged in individual cellophane-wrapped boxes or trays and placed in a master container. Any tightly sealed film wrap must be perforated by at least one small hole to permit release of air from the container during ascent to high altitudes.

Containers, built on pallets and shaped to make maximum use of the interior airplane volume, are in use. Airline containers presently in use are described in the International Air Transport Association's (IATA) *Unit Load Devices Technical Manual*. Containers for aircraft, except for the belly cargo holds, are not shaped to make maximum use of the interior volume of the airplane. One reason for this is that the individual packages that will fill the containers are generally rectangular in shape anyway. Another reason is to permit easier intermodal transport (e.g., from motor truck to the airplane and vice versa). Because of the size of aircraft loading doors and irregular aircraft cross-sections compared to surface vehicles and vessels, containerization may require this compromise.

Containerization is a system of moving goods in sealed, reusable freight containers too large for manual handling and without permanently attached wheels. The advantages include far less cargo damage and pilferage, lower packaging costs, minimized handling, and lower shipping rates. Presently, these containers may be loaded at the air freight terminal or loaded at the shipper's facility and transported by flatbed truck-trailer or railroad, or both, to the air terminal.

The critical condition for design of insulation and refrigeration systems (detachable plug-in type or permanently installed) for cargo containers is the time that the container is on the dock in the hot sun waiting for shipment. For this condition, an ambient temperature of 100°F DB is assumed. The average outside skin temperature of an unpainted metal container is about 115°F.

Under the conditions just mentioned, the 8 by 8 by 10 ft container with 0.5 in. of high-efficiency insulation (recirculating the air and considering no latent load) requires about 18,000 Btu/h of refrigeration to maintain 35°F inside and about 24,000 Btu/h to maintain 0°F inside. For quick pulldown to these temperatures of the container and fresh perishable contents (assuming prefreezing of frozen products), the capacities should increase by about 50%.

Fresh fish, shrimp, and oysters may be packed in boxes, barrels, or special containers. Proper precaution must be taken to prevent drippage from melted ice into the cargo space. Live lobsters are packed in insulated containers with saltwater seaweed. Frozen foods are always packed in insulated containers. Whole blood is shipped in specially developed containers. Insulated bags are also used.

The configurations and dimensions of two insulated containers are shown in Figure 4. Insulated with closed-cell, rigid plastic foam, the containers are a fabricated sandwich structure and are sized to fit conventional pallets and materials handling systems. The heat transfer rate for the entire standard container is 28 Btu/h·°F and 32 Btu/h·°F for the commercial size. More recent aircraft, such as the MD-11 depicted in Figure 1, use pallets 125 in. wide by 64.4, 88, and 96 in., which may be loaded to 64 in. high and retained by straps. Load capacities are 6700, 10,000, and 11,000 lb, respectively. Containers are LD-3 (half width) and LD-6 (full width), the latter having twice the capacity and width. Both are 60.4 in. deep and 64 in. high. The LD-3 width is 79 in., the volume is 158 ft$^3$, and the capacity is 3300 lb. A plug-in portable mechanical refrigerating unit may be positioned in the doorway for standby operation. Tight construction permits controlled atmosphere application. A smaller shipping unit, insulated with a foamed plastic, has inside dimensions of 45 by 21 by 24 in. (i.e., a total area of 35.1 ft$^2$ and a capacity of 13.1 ft$^3$). The heat transfer rate of the entire container is 2.8 Btu/h·°F.

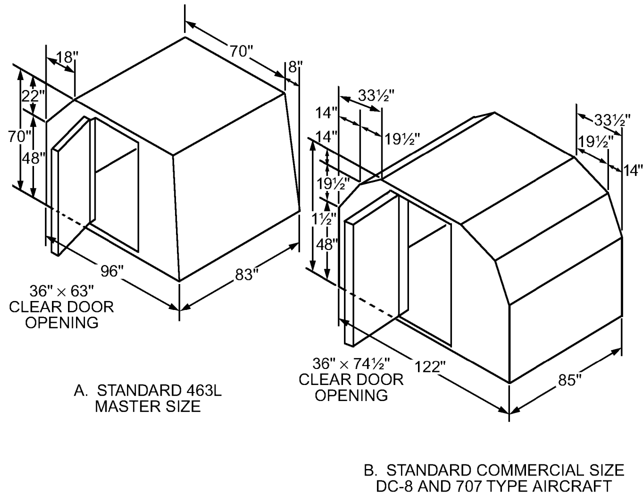


**Fig. 4 Insulated Containers Designed to Fit Configuration of Cargo Aircraft**

## TRANSIT REFRIGERATION

Many commodities must receive refrigeration in transit. In most cases, this is accomplished by a refrigerant in the package. Water ice, dry ice, and certain proprietary refrigerants are used. Because no method of transit refrigeration can economically cool a warm commodity to its desired transit temperature, all perishable items must be cooled before shipment. Flowers are generally wrapped in several layers of paper or light insulating material and kept cool by water ice. The ice (solid, chopped, or flaked) is placed in a plastic bag or wrapped in many layers of paper and tied to one of the cleats of the container. In some instances, the block of ice may be chilled to 0°F in a freezer before putting it in the package, thereby obtaining a slightly greater refrigeration capacity. Newspapers are sometimes wadded up, thoroughly wetted, and then frozen to 0°F or lower. In all cases, the paper helps absorb the ice meltage water and reduces the chances for leakage into the cargo space.

Some voids should be left in the containers to permit air circulation and uniform cooling. Boxes should be sealed to prevent air exchange. Placing the ice or water for freezing in sealed plastic bags eliminates drippage, but melting ice in open containers increases humidity, which is particularly desirable for cut flowers. A packaged refrigerant with no escape of free liquid must be used with commodities that would be damaged by water. Water ice acts as refrigerant in special blood containers.

Dry ice is used extensively with frozen products and fresh strawberries, the amount depending on the type of container and the length of the journey. Sometimes it is placed in with water ice, not only for its own refrigerating value, but also to slow down meltage of the water ice and extend its value to the end of the transit period. Dry ice alone is seldom used for flowers because its very low temperature may cause freezing damage to adjacent blooms if not properly spaced or insulated. Unless proper ventilation of the cargo compartment is provided, the use of large amounts of dry ice may cause a buildup of carbon dioxide gas in concentrations dangerous to humans and animals.

When the heat transfer rate of insulated shipping containers is known, the amount of refrigeration required can be estimated with reasonable accuracy from

$$Q = HD\Delta t$$

*where*

$Q$ = total heat transfer, Btu
$H$ = heat transfer rate of entire container, Btu/h·°F
$\Delta t$ = difference between ambient temperature and that at which product is to be carried, °F
$D$ = duration of transit, h

For example, assume the small container previously described holds 15 standard strawberry trays, each holding 13 lb of berries (195 lb total), with the fruit cooled to, and carried at, 35°F at an ambient temperature of 75°F for a transit time of 24 h:

$$H = 2.8 \text{ Btu/h·°F}$$

$$\Delta t = 75 - 35 = 40°\text{F}$$

$$D = 24 \text{ h}$$

$$Q = (2.8 \times 40 \times 24) = 2688 \text{ Btu}$$

The heat of respiration generated by the berries at 35°F is about 4000 Btu/ton·24 h (see Table 9 in Chapter 8). For 195 lb of berries 24 h in transit,

$$4000(195/2000) = 390 \text{ Btu}$$

The ice required to absorb this heat is

$$\frac{2688 + 390}{144} = 21.4 \text{ lb}$$

The amount of dry ice required would be about 11.9 lb.

These simple calculations can be made only when the thermal conductance or heat transfer rate of the container is known. It would therefore be of considerable value to all concerned—shipper, carrier, and receiver—to have this factor determined and clearly displayed for all insulated shipping containers. Such ratings have been made on truck-trailer bodies, as discussed in Chapter 29.

When package refrigeration is not available, rapid warm-up can be retarded by insulated containers or blanket insulation over stacks or pallet loads. This method has been satisfactory with some of the less perishable fruits such as peaches. Temperatures can be maintained for several in-flight hours with the proper use of these blankets. Care must be exercised in loading to ensure that insulating material is wrapped completely around the cargo and that containers are not in direct contact with hot or cold surfaces. Some cargo compartments on passenger aircraft may be cooled by the air-conditioning system, but the temperature will not be in the optimum range for most perishable commodities.

## GROUND HANDLING

All the advantages of speed can be lost if the shipper, carrier, and receiver do not follow the good handling practices that keep deterioration to a minimum.

Ground handling can amount to over 70% of the total elapsed time from shipper to receiver. To reduce this ground time, load palletization and special pallet carriers and loaders, in conjunction with improved load-handling systems aboard the aircraft, are used. Air freight terminals are now designed and built to use these new handling techniques. Combination cargo/passenger jets present unique loading techniques. A typical ground service equipment arrangement is shown in Figure 5.

Fast pickup and delivery are also essential. Because of the generally high ground temperatures at shipping point terminals and intermediate points, most perishable agricultural commodities should be cooled as soon after harvesting as possible and delivered to the air terminal in properly refrigerated vehicles, particularly if they are shipped in uninsulated containers. At the terminal, these shipments must be held at proper temperatures if prompt loading from the pickup vehicle is not possible. Holding rooms, refrigerated mechanically or by ice, should be provided. During seasonal loading peaks, refrigerated trucks or trailers may be used as temporary holding rooms. During hot weather, cargo space must be cooled before loading. Portable air-conditioning equipment, such as that used for passenger aircraft, is used.

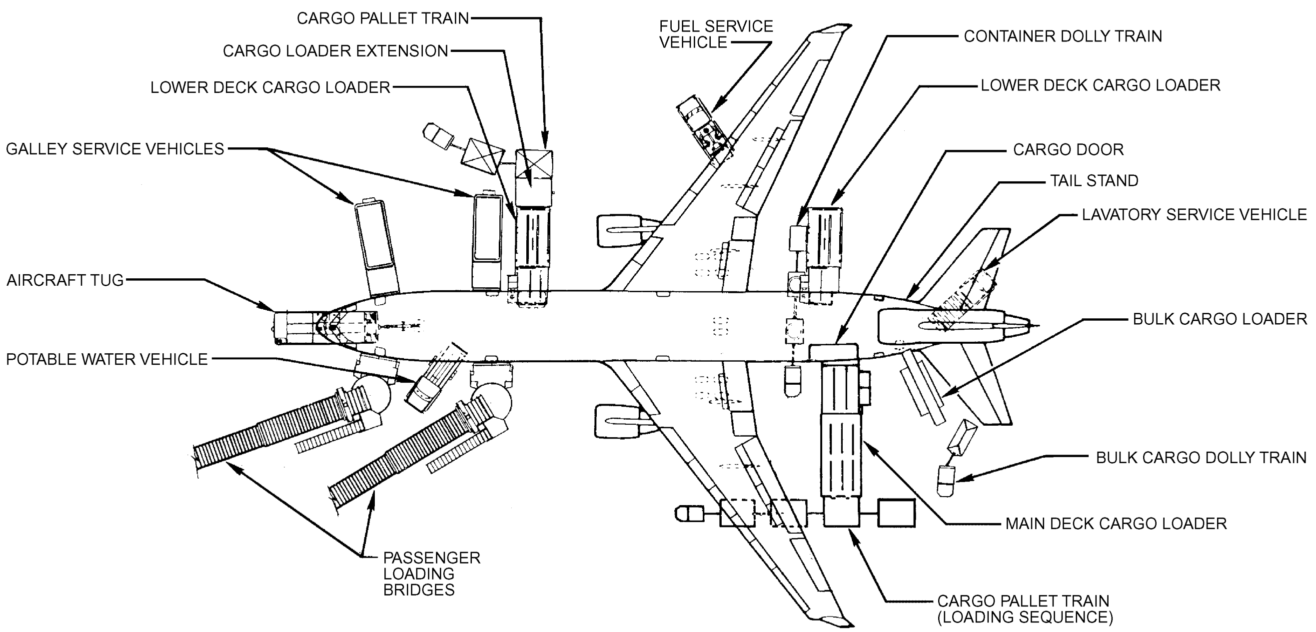


**Fig. 5 Ground Service Equipment Arrangement**

The airlines have developed rules for handling various perishable commodities. These include the temperatures desired in transit, the amount of seasonal protection needed, loading methods for various types of containers, and other factors involved in proper handling.

## GALLEY REFRIGERATION

Requirements imposed on aircraft food service by the U.S. Public Health Service (USPHS) require that potentially hazardous food carried in airplane galleys, hereafter referred to as perishable food, either is served within two hours of preparation or is stored at temperatures of 45ºF or less (USPHS 1964).

Currently it is expected that the maximum temperature for perishable food storage will remain at 45ºF until 2005. Certain other countries, notably France and Britain, are requiring temperatures as low as 41ºF. There is some discussion, including within the United States, of requiring temperatures as low as 40ºF which would require significantly more food refrigeration capacity in airplanes; part of the capacity in the short term is likely to be dry ice.

Preparation of passenger meals is done well in advance of actual catering in ground food kitchens. Meals are refrigerated and held at the catering facility. When airplanes require catering, refrigeration is often provided by packing the meals with dry ice in the service carts, which are transferred by truck from the ground kitchen to the aircraft. These service carts with the meals and dry ice inside them are then installed in the galleys as part of the airplane catering. Consequently, recent air quality surveys using $CO_2$ as a surrogate measurement have found that $CO_2$ concentrations are higher, but far from toxic, near the aircraft galleys. $CO_2$ levels are used as an indicator of the ventilation rate, considering passenger respiration release of $CO_2$. The indicator is therefore not valid in the galley areas where additional sources of $CO_2$ are located.

Most airlines flying shorter domestic routes use dry ice as a primary refrigeration method when perishable foods are to be served later in the flight. Any route of around 4 h or less can carry a perishable meal service in this way.

Most airlines flying longer domestic and international routes use vapor cycle refrigeration units installed in the galleys or in the airplane structure near the galleys that store perishable food. The current industry standard uses a self-contained refrigeration unit that uses fans to move air through heat exchangers both to provide chilled air (via the evaporator heat exchanger) for refrigeration and to remove waste heat (via the condenser heat exchanger) from the unit. Chilled air is ducted to the food storage areas in the galleys. Airflow carrying waste heat (often called exhaust air) is ducted to areas of the airplane where it can be dissipated without impact to the cabin environmental control system.

Chilled air delivered to galley units is generally handled in one of two ways. An **air-through** system delivers air to valve manifolds that interface with vent openings directly in the service carts. Its advantage is capability to provide refrigeration pulldown should perishable food temperatures temporarily exceed the limits. These systems are also more complex, and because of the many branches in the airflow, they are more prone to losses (such as cooling, airflow, pressure, and temperature) due to airflow restriction, leakage, and heat transfer through duct and cart walls.

An **air-over** system distributes air in large compartments, blanketing the service carts with chilled air. These systems are simpler and more efficient in the volume of perishables that can be refrigerated per unit of refrigeration capacity. Because food within the service cart is separated from the chilled air, pulldown performance is very poor. These systems often require complex baffling to ensure air is evenly distributed in the compartments.

Some galleys are equipped with fully contained refrigerators that are much like household units.

It is common practice to load service carts with dry ice even if the airplane galley system is equipped with chillers. Fundamentally, airplane designers do not consider food refrigeration a primary airplane function; thus, airplane systems are not well adapted to accommodate vapor cycle refrigeration machines. Also, there is less rigor in ensuring that mechanical food refrigeration systems remain functional in flight. This has the following effects:

- Vapor cycle systems in use today have difficulties in ground operations, especially in very hot environments. Galley chiller units are often located in the lower lobe or in the overhead crown areas, where air temperatures can exceed cabin and outside ambient air temperatures significantly. High air temperature for condensing refrigerant causes less-efficient chiller operation, often requiring operators to supplement mechanical refrigeration of perishables with dry ice.
- These systems are generally not robust. When not maintained diligently, they are prone to breakdowns. Dry ice is used as the backup refrigeration method.
- Flight kitchens and other catering points try to time the delivery of food to the airplane so that it arrives just in time for the food to be catered and flown away. This is critical because most caterers do not use refrigerated trucks to deliver the food to the airplane. Although caterers are provided with flight information (arrival and departure times, delays, etc.), occasionally catering trucks have to wait at the airport gate for the airplane that they are to service. To guard against having to condemn a truckload of food, airlines often require that service trolleys be loaded with dry ice.

For these reasons, despite the availability of mechanical refrigeration, there presently remains some dependence on the use of dry ice for airplane galley refrigeration. Systems are in development to decrease reliance on both dry ice and mechanical systems, but none are yet in wide production.

## REFERENCES

International Air Transport Association. Updated annually. *Unit load devices technical manual*. Montreal.

Pentzer, W.T., Jr., et al. 1958. Air transportation of fruits, vegetables and cut flowers: Temperature and humidity requirements and perishable nature. AMS *Report* No. 280. U.S. Department of Agriculture.

SAE. 1985. Animal environment in cargo compartments. ANSI/SAE *Standard* AIR 1600-85. SAE International, Warrendale, PA.

USDA. 1993. Animal Welfare. In Chapter 1 of *Code of Federal Regulations*, Title 9, Animals and Animal Products.

U.S. Public Health Service. 1964. *Handbook on sanitation of airlines: Standards for sanitation for the construction and operation of commercial passenger aircraft and servicing and catering facilities*. Publication No. 308. U.S. Public Health Service.

## BIBLIOGRAPHY

Taylor, W.P. 1990. In *Proceedings of the 25th Intersociety Energy Conversion Engineering Conference* 4:285-87. IEEE Catalog No. 90CH2942-1.

Tyree, L., Jr. 1973. Refrigerated containerized transport for "jumbo" jets. *Progress in Refrigeration Science and Technology* 4:515-525.