AEROSPACE INFORMATION REPORT	AIR1600™	REV. A
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Animal Environment in Cargo Compartments

RATIONALE

AIR1600A has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Changes in this revision are format/editorial only.

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1. SCOPE:

The environmental factors of prime importance in the transport of animals in aircraft are air temperature, humidity and carbon dioxide concentration, and of course space (or volume) limitations.

Secondary factors are air velocity, noise, lighting, etc. Pressure is not addressed herein as pressure levels and rates of change are totally dictated by human occupancy requirements.

Some basic governmental documents, such as References 1, 2 and 3, define overall requirements for animal transportation, but with very limited data on environmental requirements. Reference 4 gives some airplane characteristics measured during animal transportation from the USA to foreign destinations. Temperature and humidity profiles are indicative of airplane characteristics.

This report presents information on the temperature, humidity, ventilation, and carbon dioxide limitations and the metabolic heat release rates for animals which will allow the determination of the environment required by the animals. Design features of ventilated and nonventilated cargo compartments are presented. Methods of calculation of the temperature, humidity, and carbon dioxide environment are provided that will allow for the determination of the animal capacities of animal carrying cargo compartments. Animals are being carried in the lower cargo compartments on passenger carrying aircraft which are only provided with coarse temperature control. These compartments provide a very satisfactory environment for most animals if knowledge of the animal's requirements are matched with the compartment's capability to produce that environment.

It should be noted that although animal is the definition of cargo being considered, data is also provided for birds.

1.1 Purpose:

The purpose of this AIR is to provide information on the environmental conditions that are required for the transportation of animals in the lower cargo compartments of passenger carrying aircraft. The intent is to provide guidelines to aircraft manufacturers, and background information to air carriers, that will assist in defining suitable animal carrying environments, and which will supplement good judgement and previous experience.

Values and units are given in both U.S. Customary and SI units.

2. REFERENCES:

1. Code of Federal Regulations, Title 9 - Animals and Animal Products, Chapter 1, Subchapter A - Animal Welfare

2. IATA Live Animal Regulations, 11th Edition, January, 1984

3. FAA Order 8110.29A, Cargo Compartment Requirements for Air Shipment of Livestock, April 11, 1979

4. USDA Report, “Environmental Conditions on Air Shipment of Livestock” AAT-NE-5, dated February, 1979

5. Internal Temperatures of Chick Shipping Boxes as Influenced by Environmental Temperatures. Poultry Science, Vol. XXiX No. 2, March, 1950, Wilbur O. Wilson

6. Livestock Trucking Guide, Livestock Conservation Institute, South St. Paul

7. Boeing Commercial Airplane Company Brochure, D6-46286. “Animal Passengers in the Boeing 727 Lower Compartments”

8. ASAE Paper Number 77-4523, “Air Transport of Livestock - Environmental Needs”, 1977 Winter Meeting December 13-16, 1977

9. APHIS report 91-21, “Environmental Considerations for Shipment of Livestock by Air Freight” dated May, 1974

10. Energy and Gaseous Metabolism of the Chicken from Hatch to Maturity as affected by Temperature. J. Nutrition Volume 31, pages 35 to 50, 1946, Barott and Pringle.

11. SAE Aerospace Applied Thermodynamics Manual ARP1168, 2nd Edition, October 1969, page 110, EQ (ID-11b)

12. FAR 25.857, Cargo Compartment Classification

3. LIMITATIONS FOR VARIOUS ANIMALS:

This section discusses limitations of temperature, humidity, effective temperature, carbon dioxide, air velocity, noise and lighting. It should be noted that Reference 1 includes requirements for the welfare of animals, including transportation. Section 3.1 discusses the Reference 1 limitations on temperature, however familiarization with other aspects is also appropriate.

3.1 Temperature:

Temperature limitations are reviewed in this section as related to steady state limits and also as related to transients. Most available data is related to steady state.

3.1.1 Steady State: As a general rule, animals are reasonably comfortable at the same air temperatures as are humans. In determining the air temperature surrounding the animals one must consider the difference in temperature between inside and outside the container.

It has been observed that, when a number of animals are shipped in one container, as is the case for baby chicks, conditions within the container can be quite different from those of the surroundings. This is shown in Figure 1, which uses data from Reference 5. Such increases in temperature, as well as the increase in humidity within the shipping container, must be considered when evaluating the environment surrounding the animal. For example, if the temperature in the baby chick carton exceeds approximately 104 °F (40 °C) the potential for death due to overheat is very high. Baby turkeys have been observed to die if the temperature in the carbon exceeds 95 °F (35 °C) for more than 10 minutes.

Information published in the Code of Federal Regulations (Reference 1) includes some limits that are not to be exceeded outside the primary enclosure at “terminal facilities”. The requirements for the following animals include an 85 °F (29.4 °C) maximum and 45 °F (7 °C) minimum (see also section 3.1.2). These limits may be exceeded, with prior acclimatization, except for guinea pigs and hamsters. For these two animals the limits given in this AIR are more restrictive.

Dogs and cats
Guinea pigs and hamsters
Rabbits
Non-human Primates

Generally recognized temperature limits for various animals are included in Table 1. These are more detailed than provided by Reference 1. The Table 1 temperatures are acceptable in “normal” humidity levels of 40 to 60% RH. Higher humidity must be allowed for as discussed in section 3.3. The values given in Table 1 should be used with checks as necessary of the latest version of Reference 1.

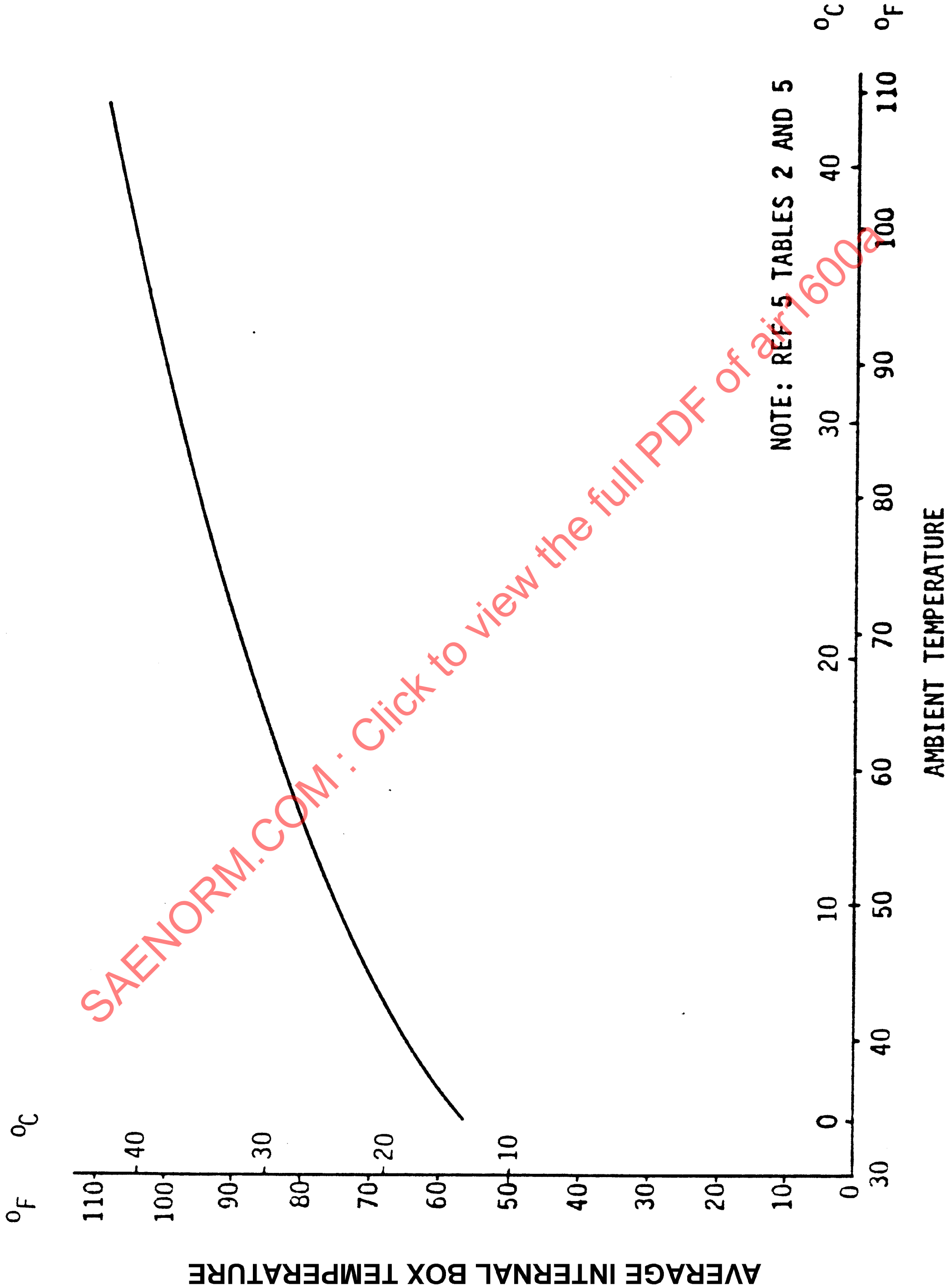

FIGURE 1 - Internal Chick Box Temperature as a Function of Ambient Temperature

TABLE 1 - Animal Temperature Limits

Animal	Temperature Limits °F	Temperature Limits °C
Ape	45 - 95	7 - 35
Badger	35 - 85	2 - 29
Bear (young)	35 - 85	2 - 29
Beaver	35 - 85	2 - 29
Birds	65 - 95	18 - 35
Bobcat	50 - 80	10 - 27
Bulldog	50 - 95	10 - 35
Canary	65 - 85	18 - 29
Capuchin monkey		
Adult	65 - 95	18 - 35
Infant	80 - 90	27 - 32
Cat	50 - 80	10 - 27
Cheetah	65 - 95	18 - 35
Chicken	60 - 90	16 - 32
Chick (baby)	70 - 85*	21 - 29*
Chimpanzee	65 - 95	18 - 35
Chinchilla	40 - 80	4 - 27
Civet	55 - 80	13 - 27
Cougar (puma)	40 - 80	4 - 27
Coyote	35 - 85	2 - 29
Dingo	45 - 85	7 - 29
Dog		
Long hair	40 - 85	4 - 29
Short hair	50 - 95	10 - 35
Dove	65 - 90	18 - 32
Duck	60 - 90	16 - 32
Duckling	70 - 85*	21 - 29*
Eagle	60 - 80	16 - 27
Ermine	45 - 85	7 - 29
Falcon	60 - 80	16 - 27
Ferret	45 - 85	7 - 29
Finch	65 - 85	18 - 29

TABLE 1 - Animal Temperature Limits (Continued)

Animal	Temperature Limits °F	Temperature Limits °C
Fox	40 - 80	4 - 27
Gazelle	65 - 85	18 - 29
Gerbil	55 - 85	13 - 29
German shepherd	40 - 85	4 - 29
Goose	60 - 90	16 - 32
Gosling	70 - 85*	21 - 29*
Great Dane	45 - 95	7 - 35
Green monkey		
Adult	65 - 95	18 - 35
Infant	80 - 90	27 - 32
Guinea pig	45 - 80	7 - 27
Hamster	50 - 85	10 - 29
Hawk	60 - 80	16 - 27
Hornbill	60 - 80	16 - 27
Hummingbird	65 - 95	18 - 35
Hunting dog	40 - 85	4 - 29
Hyena	45 - 85	7 - 29
Jaguar	65 - 95	18 - 35
Jay	65 - 85	18 - 29
Jerboa	55 - 90	13 - 32
Lemur monkey		
Adult	65 - 95	18 - 35
Infant	80 - 90	27 - 32
Leopard	65 - 85	18 - 29
Lion	65 - 85	18 - 29
Lynx	60 - 80	16 - 27
Magpie	65 - 85	18 - 29
Manx	50 - 80	10 - 27
Marmoset monkey		
Adult	65 - 95	18 - 35
Infant	80 - 90	27 - 32
Marmot	40 - 80	4 - 27
Marten	40 - 80	4 - 27
Mink	40 - 80	4 - 27
Mouse	55 - 90	13 - 32
Muskrat	40 - 80	4 - 27

TABLE 1 - Animal Temperature Limits (Continued)

Animal	Temperature Limits °F	Temperature Limits °C
Mynah	65 - 85	18 - 29
Ocelot	65 - 95	18 - 35
Opossum	55 - 90	13 - 32
Orangutang	70 - 95	21 - 35
Otter	40 - 80	4 - 27
Owl	60 - 80	16 - 27
Parrot	65 - 90	18 - 32
Peafowl	60 - 80	16 - 27
Pheasant	65 - 95	18 - 35
Pigeon	65 - 85	18 - 29
Polecat	45 - 85	7 - 29
Poodle	50 - 85	10 - 29
Porcupine	40 - 80	4 - 27
Pug	50 - 95	10 - 35
Quail	65 - 85	18 - 29
Rabbit	35 - 85	2 - 29
Raccoon	40 - 80	4 - 27
Rhesus monkey		
Adult	65 - 95	18 - 35
Infant	80 - 90	27 - 32
Rodent	55 - 85	13 - 29
Sable	40 - 80	4 - 27
Sandpiper	65 - 85	18 - 29
Shrew	55 - 85	13 - 29
Spider monkey		
Adult	65 - 95	18 - 35
Infant	80 - 90	27 - 32
Squirrel	45 - 85	7 - 29
St. Bernard	35 - 85	2 - 29
Standard poodle	45 - 85	7 - 29
Terrier	50 - 95	10 - 35
Turkey	60 - 80	16 - 27
Turkey poult	70 - 85*	21 - 29*
Vicuna	50 - 80	10 - 27
Waxbill	65 - 85	18 - 29
Weasel	40 - 80	4 - 27

TABLE 1 - Animal Temperature Limits (Continued)

Animal	Temperature Limits °F	Temperature Limits °C
Wild dog	45 - 85	7 - 29
Wolf	35 - 85	2 - 29
Wolverine	35 - 85	2 - 29

*This is compartment temperature. Temperature within the carton will be 90 - 100 °F (32 - 38 °C).

With correct packaging, the above animal requirements represent compartment limits.

3.1.2 Transients: As is implied by the Department of Agriculture in Reference 1, transient excursions beyond the limits set are acceptable. Of course the magnitude must be limited. For Reference 1 animals (see section 3.1.1), an excursion above 85 °F (29.4 °C) or below 45 °F (7.2 °C) is required by Reference 1 to be limited to 45 minutes.

The Livestock Conservation Institute has published information on a Livestock Weather Safety Index for use by the trucking industry, Reference 6 (See Figure 2). Reference 6 data is directed at transportation of cattle, sheep and hogs, whereas this AIR is primarily directed at smaller animals. However, the data is of use for comparison. Reference 6 recommends delay in shipment if the conditions in the “Emergency” region are predicted for the transportation time period.

Animals transported by air encounter a different exposure than do those transported by truck. Aboard the truck, they are generally exposed to the severe environment for the entire period of confinement on the vehicle. On the airplane, the situation is different in that the severe conditions exist with the airplane on the ground or at low altitude.

Transient conditions, primarily involving excitement during loading, are allowed for by the inclusion of excitement factors in Section 4, Metabolic Heat Rates.

With additional risk of animal loss, acceptable transient temperature could be revised by approximately 6 °F (3.3 °C) as indicated by translation from the ALERT/DANGER boundary of Figure 2 to the DANGER/EMERGENCY boundary.

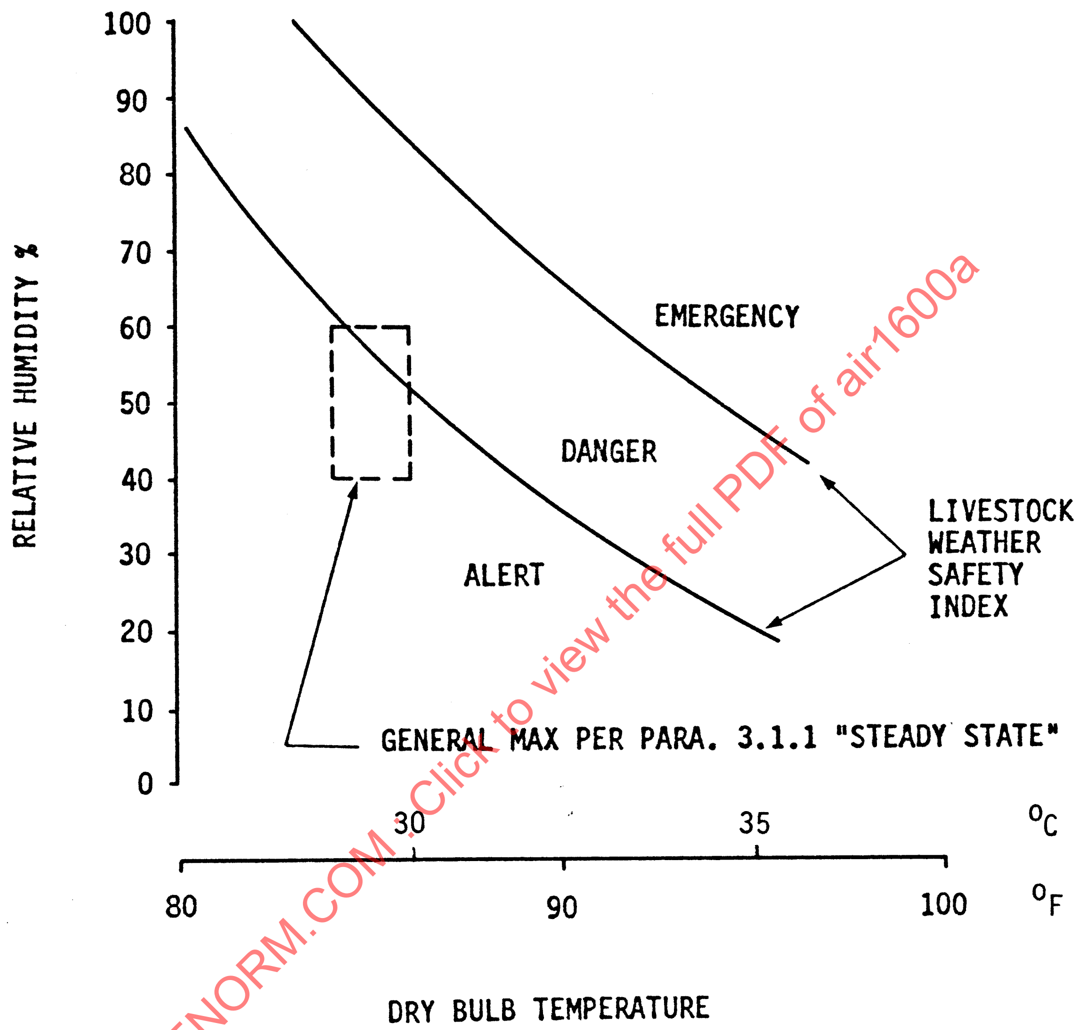

FIGURE 2 - Livestock Limitations Per Reference 6

3.2 Humidity:

To maintain control of the body temperature, it is necessary to discard heat released during the metabolic process occurring within the animals. As discussed under the section dealing with Metabolism, heat is lost by Sensible and by Latent heat losses. In a confined compartment, the released sensible heat raises the compartment temperature and the latent heat raises the compartment absolute humidity. The sum of the heat lost through sensible and latent processes must equal the metabolic heat if body temperature control is to be realized. Sensible heat transferred is dependent on the temperature difference between the animal's body and its surroundings. Thus, as the temperature of the air surrounding the animal approaches the animal's body temperature, less heat is lost as sensible and more must be rejected as latent. Since the heat that can be rejected as latent decreases as the relative humidity approaches 100 percent, a need exists to avoid the combination of high temperature and high humidity if body temperature control is to be realized. For short periods, the animal can store a small amount of heat within its body to raise body temperature slightly to again release some sensible heat. However, great discomfort is experienced and fatality can occur within a short period of time if these conditions are sustained.

Normally there is no lower limit on humidity for animal transportation. The maximum allowed humidity is determined by heat balance.

3.3 Effective Temperature:

The combined effect of temperature and humidity can be defined as an "Effective Temperature". This concept is used for human comfort analysis. This same concept can be applied to animals with the limitation that sweat (latent heat loss) characteristics are a variable. Horses sweat in a manner similar to humans, whereas cattle, sheep, hogs, dogs, etc. are classified as "slightly sweating". With this limitation, the temperature increases in Table 2 can be used to allow for high humidity inn defining a compartment (effective) temperature for animals. Industry data on 150 lb (68 kg) hogs ("slightly sweating") indicated that a 95 °F (35 °C) air temperature and 100% relative humidity causes an effective increase in temperature of only 5.4 °F (3 °C). Therefore Table 2 will be conservative for these "slightly sweating" animals. Table 2 data is from reference 7.

The effective temperature increases, from Table 2, is added to the compartment temperature. This new temperature is to be compared to the allowable animal temperature limits of Table 1. A discussion of how to calculate compartment temperature is found in Section 5.1.

TABLE 2 - Effective Compartment Temperature Increase to Allow for High Humidity
Effective Temperature Increase, °F (°C)

Relative Humidity	Dry Bulb Temperature, °F (°C) 79 (26.0)	Dry Bulb Temperature, °F (°C) 82 (28.0)	Dry Bulb Temperature, °F (°C) 86 (30.0)	Dry Bulb Temperature, °F (°C) 90 (32.0)	Dry Bulb Temperature, °F (°C) 93 (34.0)	Dry Bulb Temperature, °F (°C) 97 (36.0)
70%	1.3 (0.7)	2.2 (1.2)	3.1 (1.7)	4 (2.2)	5 (2.8)	6.1 (3.4)
80%	2.2 (1.2)	3.6 (2.0)	5.2 (2.9)	6.7 (3.7)	8.6 (4.8)	10.4 (5.8)
90%	3.6 (2.0)	5.8 (3.2)	8.3 (4.6)	10.8 (6.0)	13.9 (7.7)	17.3 (9.6)
100%	5.9 (3.3)	8.6 (4.8)	11.9 (6.6)	14.9 (8.3)	19.3 (10.7)	28.8 (16.0)

3.4 Carbon Dioxide:

Carbon dioxide is generated continuously by animals as a metabolic by-product. Air ventilation rates must be kept high enough, or animal loads limited so as to prevent unacceptable concentrations of carbon dioxide.

Carbon dioxide concentration limits are defined as 5% (approaching lethal) in Reference 8. For humans, 0.5% is considered the normal maximum. Other literature, discussing the 5% value, describe it as critical. This value is the design standard for airplane lower cargo compartment carriage of animals.

Animals should not be loaded in the same compartment as dry ice as this can produce dangerous quantities of carbon dioxide.

3.5 Air Velocity:

As with humans, drafts across the animals should be kept to a minimum. However, air movement is desired in order to avoid stagnant conditions surrounding the container. A typical passenger cabin air velocity would be approximately 40 fpm (0.20 m/s). This is unlikely to be exceeded in most lower lobe cargo compartments. Air velocity should be sufficient to prevent development of a local environment differing significantly from that of the overall compartment conditions.

3.6 Noise:

Tests have been run with various species of animals in a simulated cargo compartment during which simulated jet noise of 110 decibels was generated. The animals were exposed for ten hours or more without adverse effects. The animals were observed for two weeks after the exposure and showed no detectable ill effects. However, excessive noise during loading can cause the animal distress. Exposure to such noises should be kept to a minimum.

3.7 Lighting:

Lighting requirements are probably seldom critical, however for most animals, a darkened compartment would be preferable during transportation.

4. METABOLISM OF ANIMALS:

Metabolism is an important factor in evaluating the animal environment as this generates heat and also impacts cargo compartment humidity due to moisture release. Metabolic rates are defined with supplementary data for baby chicks. A discussion is also included dealing with airplane ground operation.

4.1 Sensible and Latent Heat:

Metabolic heat is discarded by a combination of radiation and convection processes (sensible heat) and by evaporation (latent heat). The total available heat loss must equal the heat production rate or body temperature will rise, leading to discomfort, and, eventually, to death.

Data published on results of animal studies indicate that the metabolic heat release of an individual animal is proportional to its weight. Also noted is that during any type of shipping, e.g., truck, trail, air, etc., the resultant excitement causes the metabolic heat release to increase. The increase can be as high as 2 to 5 times the metabolic rate of animals at rest. The increase is least for large animals and most for the small animals.

The animal heat is released into the surrounding air as a combination of sensible and latent heats, the exact proportion depending upon the air temperature. The sensible and latent heat production rates for some of the common animals are given in Reference 8 and in other studies or reports. Reference 9, which has been used as a standard for many years, has been superseded by Reference 8. It should be noted that the data search showed that there are differences among sources, however Figures 3 and 4 utilize primarily Reference 8, and should be used with no additional factor applied.

Metabolic rates, for animals not included in Figures 3 and 4, can be estimated from the generalized data of Figures 5 and 6. Excitement factors are included. A factor of 5 is included for a small animal and a factor of 2 for a large animal. Compartment temperature is therefore calculated (see Section 5.1) including the excitement heat loads, and then compared to the allowable temperatures of Section 3.1. Recordings made during shipment of cattle and hogs in the cabin of a cargo airplane suggest that the excitement associated with the loading has disappeared by the time cruise altitude has been reached.

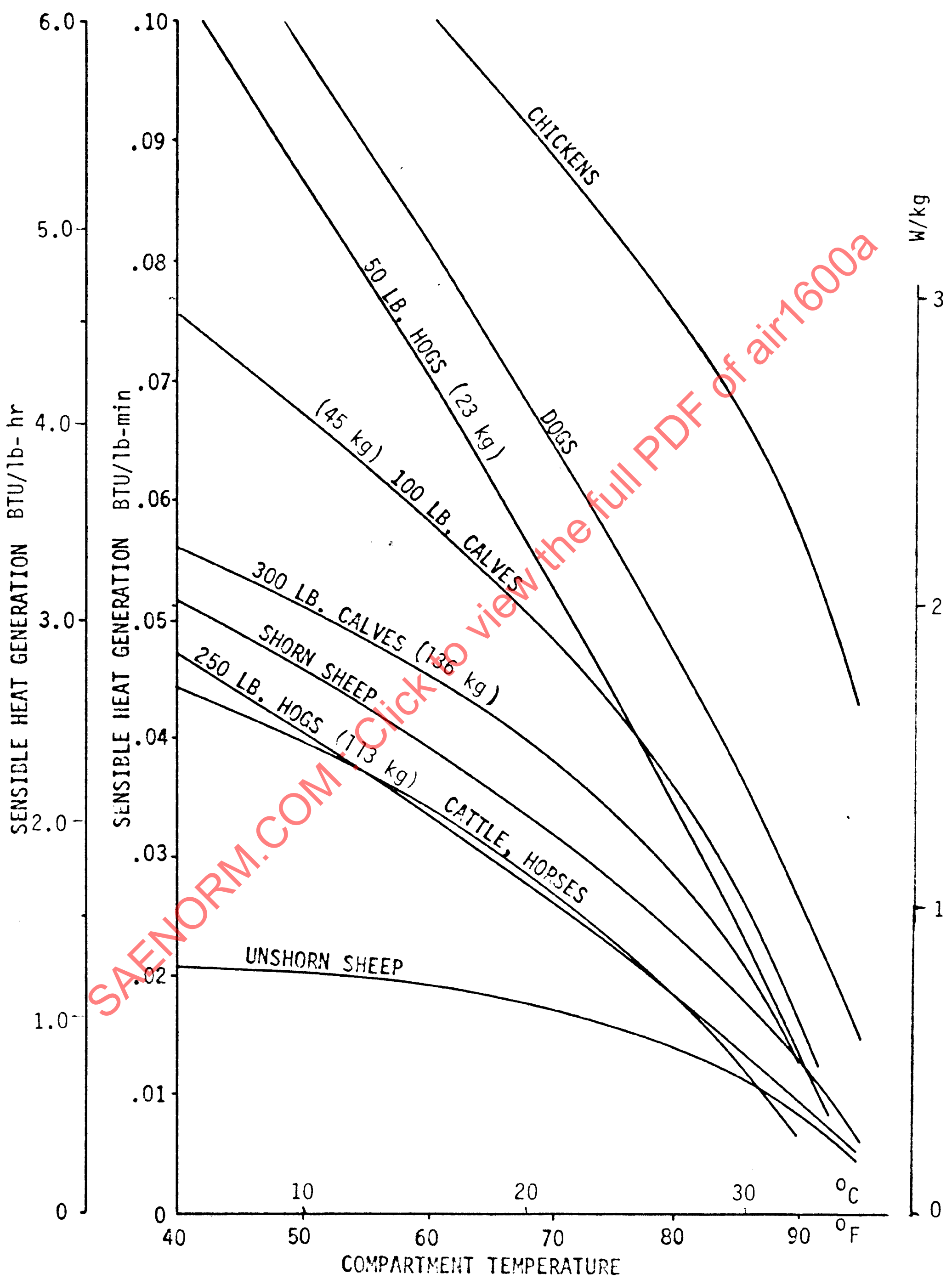

FIGURE 3 - Sensible Heat Production Rates

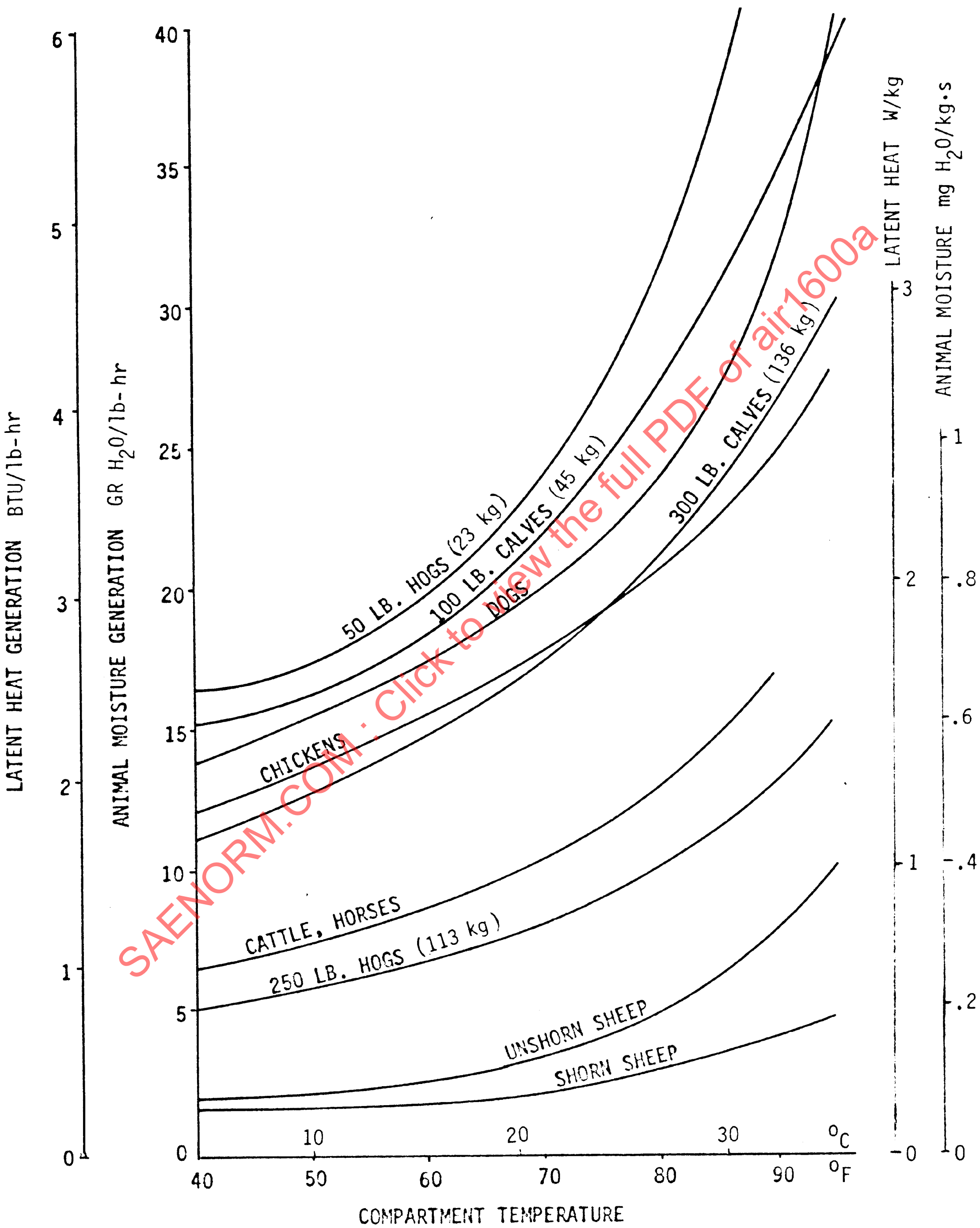

FIGURE 4 - Latent Heat/Moisture Rates

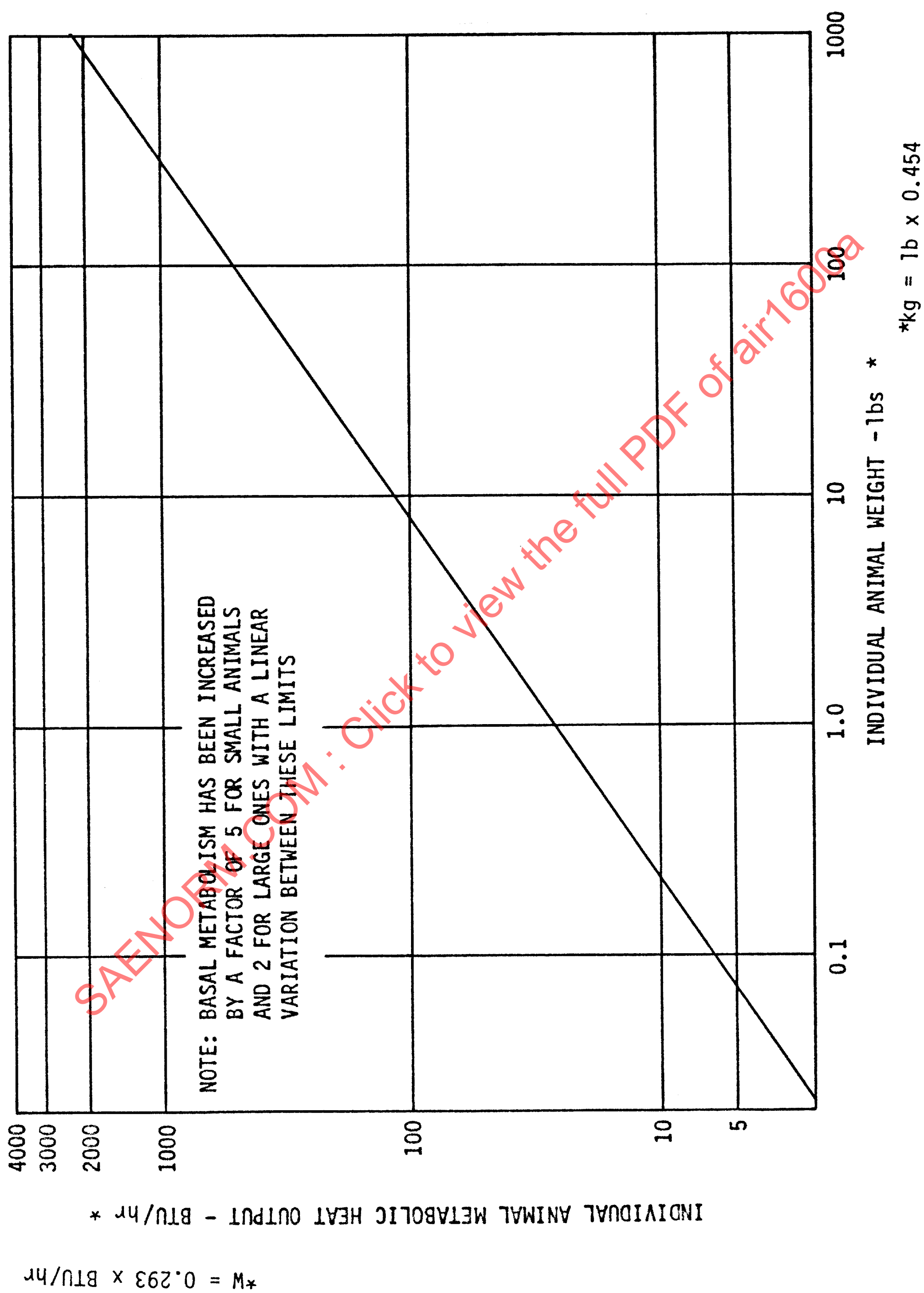

FIGURE 5 - Typical Metabolic Heat Output During Animal Shipment Versus Individual Animal Weight

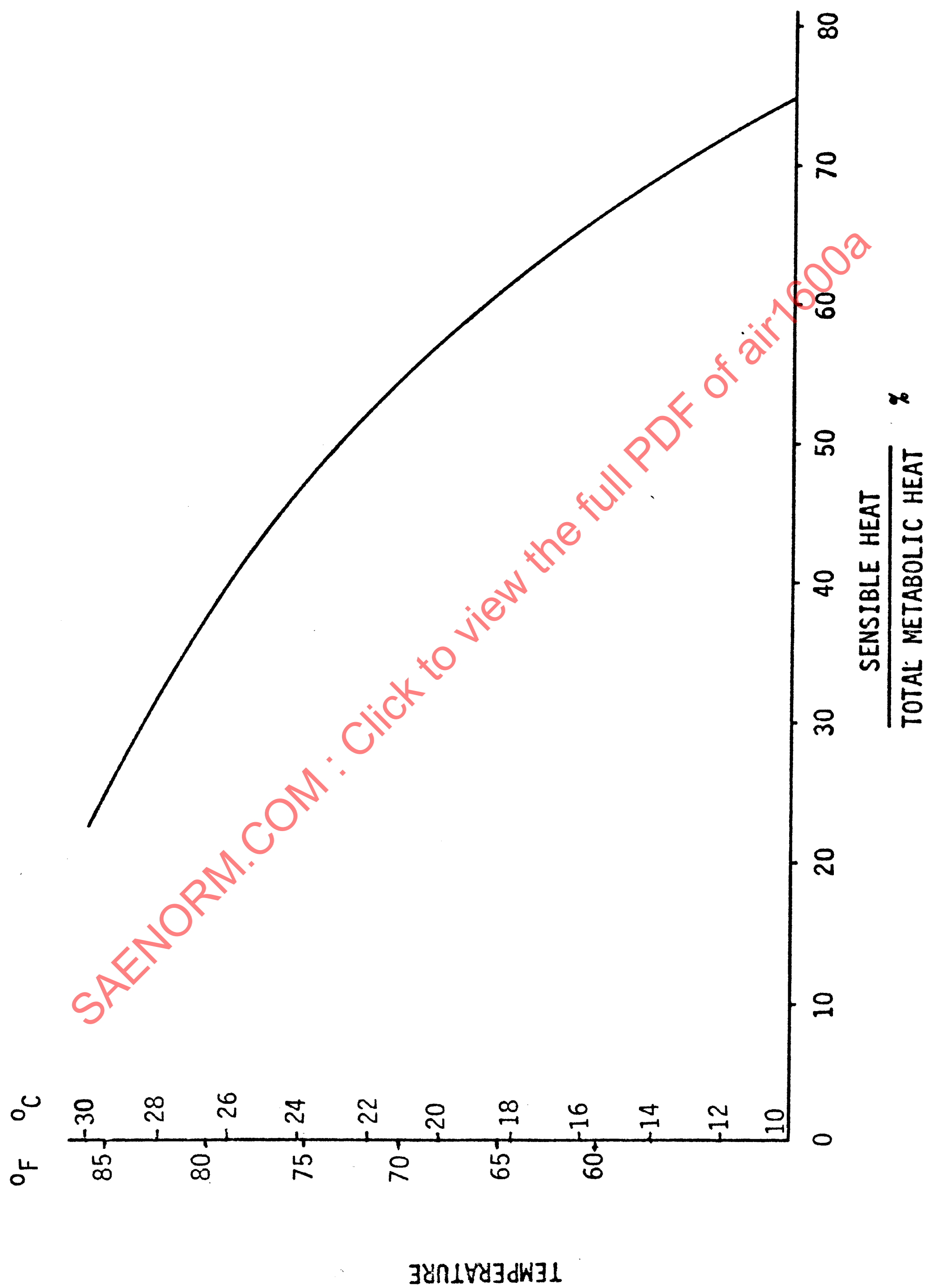

FIGURE 6 - Ratio of Animal Sensible Heat to Metabolic Heat as a Function of Temperature

4.2 Metabolism for Baby Chicks:

The following Table gives metabolic data for baby chicks (day old), based on Reference 10:

TABLE 3

Environmental Temperature °F	Environmental Temperature °C	Heat Produced Per Chick BTU Per Hour	Heat Produced Per Chick Watts
65	18.3	1.84	0.54
70	21.1	1.84	0.54
75	23.9	1.72	0.50
80	26.7	1.47	0.43
85	29.4	1.20	0.35
90	32.2	0.94	0.28
95	35.0	0.79	0.23
100	37.8	0.86	0.25

4.3 Ground Operation:

The conditions on the ground in a cargo compartment between the time of loading the animals in the compartment and takeoff are very critical to the animals' welfare for the following reasons:

1. The animals have just been loaded and are probably excited, elevating their metabolic rate.

2. There is usually no ventilation to cool the compartment and remove moisture.

3. On a hot day, there is no condensation on the door frames to remove moisture and limit humidity, as will occur in flight.

4. Other cargo, which has been exposed to very hot or very cold temperature, may be loaded in the same compartment, thereby giving localized conditions determining metabolic sensible/latent balance different from average conditions. Extreme variations should be avoided.

5. On a hot day, local animal environment can be adversely affected by nearby airplane ducting systems carrying hot air. For example, the on-board Auxiliary Power Unit (APU) may be delivering hot bleed air to air conditioning packs, using ducts in close proximity to cargo walls. This design situation should be avoided, or allowed for in animal loading, as this also will impact local animal metabolic balance and cooling requirements.

4.3 (Continued):

The temperature problem during ground conditions can be severe due to factors discussed above. This state should be limited in time duration to approximately 30 minutes unless special precautions are taken to alleviate the adverse environment for the animal.

5. METHODS OF CALCULATION:

Calculation of the temperature and relative humidity should consider the transient conditions from animal loading, climb, throughout cruise, during descent, and after landing until the animals are removed. This type of analysis can only be made practical by using transient computer programs.

5.1 Compartment Temperature:

The temperature in the cargo compartment is based on a transient heat balance. Initial conditions for temperature analysis are established when animals are loaded and the cargo compartment door is closed. The result of the compartment temperature analysis is compared to the allowable temperatures of Section 3.1 after allowing, where necessary, for humidity effects described in Section 3.3.

The heat balance must consider heat transfer through cargo compartment linings to the air in the cheek area or to cabin exhaust air if that air is circulated around the compartment; also to be considered are conduction through the cargo door (and the surrounding structure) and conduction through the floor panels and structure to the skin. The input heat load is the sensible metabolic load from the animals. However, the latent metabolic load must be considered if condensation takes place on compartment surfaces where surface temperatures and total heat transfer may be affected by such condensation.

Ventilation air affords a significant heat sink and must be considered as a strong transient influence as it varies throughout the flight. The amount of ventilation will vary depending upon the cargo compartment classification. It may exist all the time or only when the airplane is pressurized.

External heat sources which could affect compartment temperatures such as a nearby engine bleed duct must also be considered in the transient analysis.

5.2 Method of Estimating Compartment Humidity:

The relative humidity in the compartment varies as a function of the animal latent heat load, the ventilation rate, and the condensation of moisture on cold surfaces in the compartment. A transient analysis must be made and will start when the compartment is sealed and continue until animals are unloaded.

Where compartments are unventilated or ventilated at a low rate until the airplane is pressurized, relative humidity will build up rapidly and will stabilize only when the moisture ventilated overboard, and that condensed on the cooler surfaces of the compartment, equals the latent metabolic animal load.

The analysis of heat transfer in the compartments must allow for the complexity of heat transfer paths and transient sink temperatures, and for the amount of condensation which will affect relative humidity predictions.

Empirical data should be obtained during aircraft testing. These data should include temperature, ventilation rates, humidity and heat loads, all of which are necessary in order to define a good computer model. The use of a water vapor generator would add intelligence to the model, provided the generation were not too localized in the compartment.

5.2.1 Non-Ventilated Areas: The humidity in unventilated compartments will depend on the moisture generated by the animal load and the condensation of moisture on the cooler surfaces of the compartment.

The specific humidity can be calculated by balancing the input moisture against the moisture removal by condensation.

Moisture input from animals is a function of the animal metabolism and the compartment temperature. Section 4 defines moisture generation by animals.

For non-ventilated areas, moisture will stabilize when the rate of condensation on cold walls is equal to the moisture generated in the compartment.

A basic condensation equation derived from Reference (11) is:

$$n = \frac{2.9\,h\,(P_v - P_w)\,A}{P_b} \qquad \text{(Eq.1)}$$

5.2.1 (Continued):

where:

- m = mass of water condensed, lb/hour (g/s)
- h = heat transfer coefficient at the cold surface, BTU/hour-°F ft^2 (W/°C·m^2)
- P_v = water vapor pressure of the compartment, psi (Pa)
- P_w = water vapor pressure at the surface, psi (Pa)
- A = area of cold surfaces, ft^2 (m^2)
- P_b = barometric pressure, psi (kPa)

Note: Constant 2.9 in equation (1) becomes 6.9 x 10^{-4} for SI units

The relative humidity can be determined by solving for P_v when m is equal to the moisture generated by the animals. It is necessary to establish the dry bulb temperature in the compartment on the basis of sensible heat generated and transferred to the colder surfaces.

Thus the water vapor pressure of the compartment is:

$$P_v = \frac{M\,P_b}{2.9\,h\,A} + P_w \qquad \text{(Eq.2)}$$

where:

M = latent heat load of the cargo (equals m), lb water/hour (g/s)

Note: Constant 2.9 in equation (2) becomes 6.9 x 10^{-4} for SI units.

Given P_v and the dry bulb temperature in the compartment, relative humidity may be calculated by dividing P_v by the saturated vapor pressure of water at the compartment dry bulb temperature (see Section 5.1).

$$RH = \frac{100\,P_v}{\text{Saturated Vapor Pressure}} \qquad \text{(Eq.3)}$$

5.2.2 Ventilated Areas: It is assumed that the ventilation air does not add moisture to the compartment, that is, it enters at zero humidity. This is a reasonable assumption during airplane cruise. Steady state relative humidity in a ventilated compartment can be calculated by adding a ventilation term to equation (1), thus:

$$M = \frac{2.9\ h\ A\ (P_v - P_w)}{P_b} - W \qquad \text{(Eq.4)}$$

where W is the ventilation rate lb/hour (g/s), r is the specific humidity in the compartment and M equals m.

Since $r = 0.622\ P_v/P_a$ (Eq.5)

Where P_a = partial pressure of air in the compartment (equals P_b - P_v) and if then P_a is considered to be approximately equal to P_b, then by substituting (5) into (4),

$$P_V = \frac{(2.9\ h\ A\ P_w) + M\ P_b}{(2.9\ h\ A - 0.622\ W)} \qquad \text{(Eq.6)}$$

Use equation (3) to calculate relative humidity in the compartment.

Note: Constant 2.9 above becomes 6.9×10^{-4} for SI units.

5.3 Method for Estimating Carbon Dioxide:

The following applies to both unventilated and ventilated areas.

5.3.1 Carbon Dioxide Concentration: Carbon dioxide is generated continuously by animals as a metabolic by-product. The CO_2 production rates for various animals are given in Figure 7.

In order to calculate carbon dioxide concentration in a cargo compartment, the first step is to calculate the total amount of carbon dioxide being generated by the animal using the actual animal data and Figure 7.

Then, for an unventilated compartment, carbon dioxide concentration in the compartment is given by the equation:

$$C_r = \frac{100\ q_r t}{V_c} \qquad \text{(Eq.7)}$$

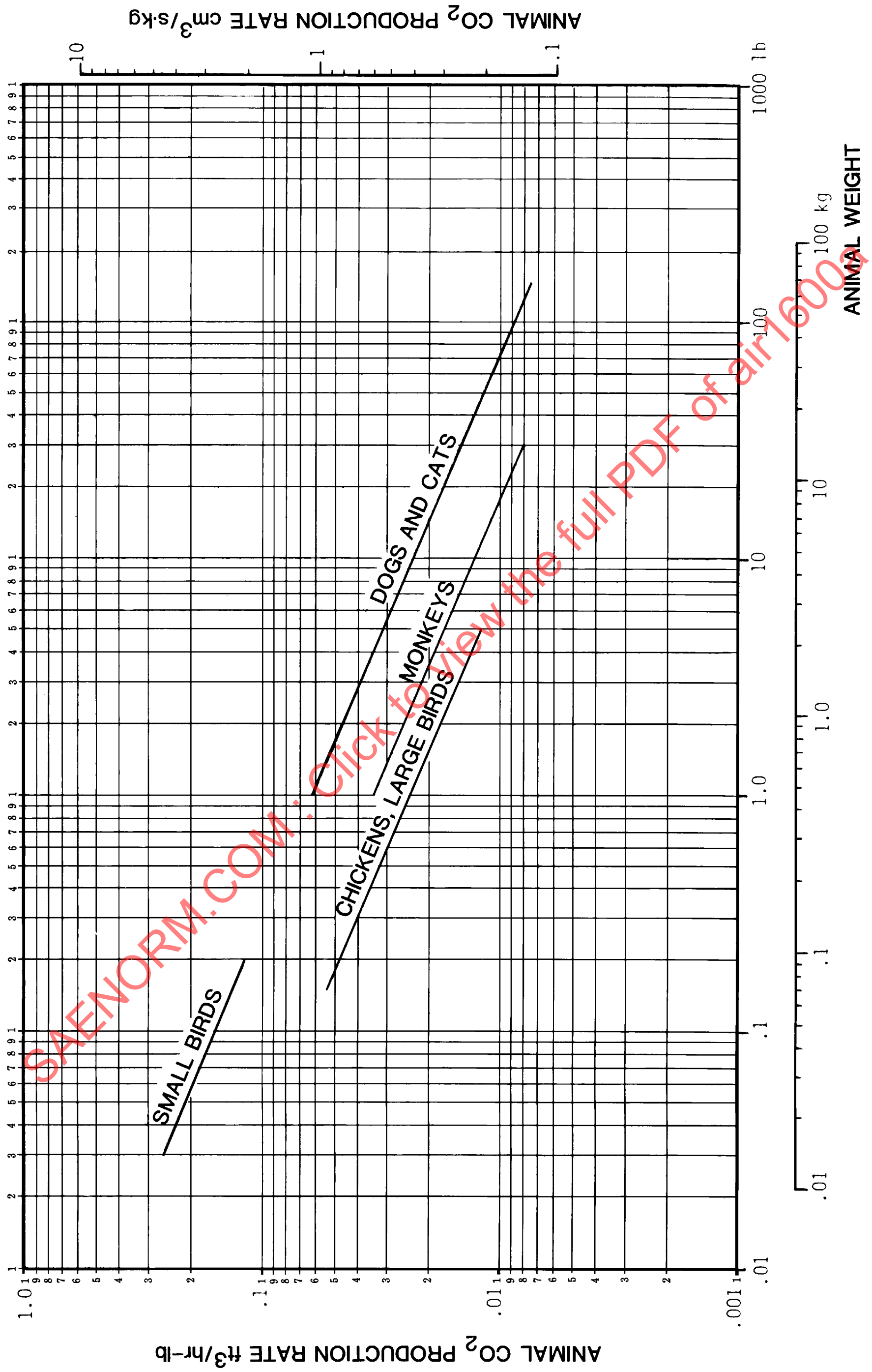

FIGURE 7 - Animal CO_2 Production Rates

5.3.1 (Continued):

where: C_r = carbon dioxide concentration by volume, percent
q_r = rate of carbon dioxide generation for all animals in the compartment, ft^3/hour (m^3/s)
V_c = the free air volume within the compartment, ft^3 (m^3)
t = time, hour(s)

A CO_2 concentration above 5% by volume is considered to be critical and should not be exceeded. Therefore, assuming that some circulation within the compartment is provided to avoid stagnant pockets of CO_2, the maximum confinement time for the animals in a cargo compartment, t_{max}, is given (from equation 7) by

$$t_{max} = 0.05 \frac{V_c}{q_r} \quad \text{(Eq.8)}$$

The confinement time is the total time for which animals are in the cargo compartment with doors closed.

If there is insufficient movement of air within the unventilated compartment or animal containers, then confinement time given by equation (8) will be too optimistic. This is because, in this case, individual containers may have higher CO_2 concentration than average.

For a ventilated compartment, carbon dioxide concentration in the compartment is given by:

$$C_r = \frac{100\, q_r}{F} [1 - e^{-Ft/V_c}] \quad \text{(Eq.9)}$$

where: F is the ventilation rate in ft^3/hour (m^3/s)

For ventilation rate greater than 20 q_r, the maximum confinement time is unlimited. For lower values of ventilation rate, the maximum confinement time can be determined by solving for t in equation (9).

5.3.2 Consideration of Airplane Variables: There are airplane variables which can significantly affect the evaluation of CO_2 accumulations and their resultant limitations on animal transportation. These include variables such as the expected in-service increase in air leakage, the normally localized characteristic of leakage and the airplane flight mission profile. These variables are not quantified in the following discussion, but should be considered in the evaluation of CO_2 limitations.

For compartments where the ventilation rate for the maximum livestock load turns out to be less than 20 q_r it is likely that it will be significantly affected by the variation in compartment overboard leakage rate. Compartments with no ventilation system are in this category. It is expected that the leakage rates determined per Section 5.2 Tests will be representative of new door seals. In-service operation will tend to eventually increase these leakage rates.