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U.D.C. 629.13.067.4 : 656.7.072 : 628.84

CP No.1136*
November 1969

AIRFLOW RATE REQUIREMENTS IN PASSENGER AIRCRAFT

by

E. A. Timby

E.P. Dept., R.A.E., Farnborough

SUMMARY

Airflow requirements for cabins of passenger transport aircraft are considered from the aspects of breathing, temperature control, odour control, pressurisation and equipment cooling. In supersonic aircraft the consequences of a pressurisation failure and the requirements of equipment cooling are likely to prevent much reduction in airflow below current figures. In subsonic aircraft the airflow could be reduced for pressurisation but is likely to be dictated by odour control on which information is lacking under representative conditions. The minimum engine air bleed rate would occur for a system which recirculates and purifies a proportion of the cabin air. Development of cabin air distribution systems would be required if airflow is to be reduced.

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*Replaces R.A.E. Technical Report 69228 - A.R.C. 31984

CONTENTS

1 INTRODUCTION

The increasing size and speed of transport aircraft is leading to larger capacity cabin conditioning systems and consequent greater power and weight. Designs which have been developed for smaller, slower aircraft may not be optimized for new conditions and need to be reviewed from time to time.

A fundamental parameter in all conditioning systems is the fresh airflow rate to be supplied per passenger, which at present is specified by operators[1] as 1.2 lb/min (9.1 g/s) per passenger during flight and 0.5 lb/min (3.8 g/s) during taxi conditions.

The air supply is required to fulfil various purposes;

(1) Control oxygen and carbon dioxide levels for breathing.
(2) Control passenger temperature (without gradients or draughts).
(3) Clear obnoxious odours.
(4) Meet pressurisation requirements.
(5) Control equipment temperature.

It has already been suggested that the minimum partial pressure of oxygen and the maximum partial pressure of carbon dioxide[2,3] to provide a satisfactory breathing atmosphere could be met with a lower airflow than is the present practice[4]. This Report considers the supply rate in terms of all the requirements.

The provision of conditioning on the ground could be important from a passenger appeal aspect. One way of providing this, apart from the provision of auxiliary power units to supply pressure air in lieu of the engines, is to use a recirculation system with a vapour cycle refrigerator system.

It is concluded that from a purely breathing aspect the fresh air supply per passenger could be reduced to the order of 0.25 lb/min (1.89 g/s). In supersonic aircraft pressurisation needs in emergency conditions and equipment cooling requirements will probably prevent any large reduction in the total air supply. However in subsonic aircraft cruising below 40000 ft (12192 m) some reduction, possibly up to 50% could be made.

Odour control will determine the passenger airflow requirement and information is lacking on this under representative aircraft conditions. The fresh air requirement per passenger could be reduced while maintaining acceptable odour control by use of a recirculation system incorporating purification equipment. This also needs further investigation.

The reduction of the total air supply per passenger would entail development work on distribution systems in order to maintain acceptable temperature gradients within the cabin.

2 AIR SUPPLY RATE REQUIRED FOR BREATHING

The cabin air composition and the corresponding partial pressures resulting from a period of 1 hour occupancy have been calculated for cabin volumes of 45, 50 and 75 ft^3 (1.274, 1.416 and 2.12 m^3) per passenger, which are representative values for current aircraft Fig.1, and fresh air supply rates from 0.1 to 1.0 lb/min (0.756 to 7.56 g/s). The assumptions and method of calculation are given in Appendix A.

The results of the calculations are shown in Table 1 and Figs.2-5. A typical plot of the partial pressures of oxygen and carbon dioxide over a period of 1 hour is shown in Fig.2. It will be noticed that, except at the minimum flow rate of 0.1 lb/min (0.756 g/s), after 1 hour conditions are virtually stable. Fig.3 shows the effect of cabin volume after 1 hour and it will be seen that above a flow rate of 0.2 lb/min (1.51 g/s) there is negligible effect due to changing the volume. Fig.4 shows the effect of varying the flow rate for a cabin volume of 50 ft^3 (1.416 m^3) per passenger. The partial pressure of carbon dioxide increases rapidly below a flow rate of 0.5 lb/min (3.78 g/s), but does not exceed the recommended British limit until a flow of less than 0.1 lb/min (0.756 g/s) is reached. Although the value of the partial pressure of oxygen decreases rapidly with flow rates below 0.5 lb/min (3.78 g/s) it would not be outside the proposed limit until the rate of supply is less than 0.1 lb/min (0.765 g/s).

The variation of relative humidity after 1 hour is shown for a cabin volume of 50 cu ft (1.416 m^3) per passenger. This shows that the original relative humidity is maintained at an airflow of about 0.25 lb/min (1.89 g/s). For airflows less than this the relative humidity increases rapidly while for higher flows it decreases. Table 1 shows that the effect of cabin volume per passenger is small as is the effect of doubling the initial water concentration which was investigated at a cabin volume of 75 cu ft (2.12 m^3) per passenger.

The results show that for breathing requirements the airflow rate per passenger could be reduced to about 0.1 lb/min (0.756 g/s) per person without exceeding the partial pressure limits, although at this rate the cabin water content would increase. At a flow rate of about 0.25 lb/min (1.89 g/s) per passenger the steeply sloping parts of the partial pressure curves are not approached and the relative humidity remains at about the initial value so that this would appear to be a reasonable minimum figure. The above assumes that the air supply to the cabin is dry and that there is a good distribution system so that each passenger gets an equal amount of air. The value of 25% RH could however possibly lead to a 'wet' aircraft in the subsonic case with the attendant corrosion and weight problems.

3 CABIN TEMPERATURE AND TEMPERATURE GRADIENTS

The amount of ventilation required to obtain a satisfactory mean cabin temperature with acceptable temperature gradients is dependent upon the internal heat load, the heat flow through the cabin walls, the minimum cabin air inlet temperature for comfort (assuming that it is available from the generation system), the specific heat of the ventilating medium (air in the present study although mixtures such as oxygen/helium could be considered) and the design of the distribution system.

For a particular aircraft cabin the design of the distribution system can have a very large effect. For example, in tests on an experimental representative Mach 2.2 transport aircraft cabin[6], changes in the distribution system enabled a reduction in fresh air ventilating flow from 1.8 lb/min (13.6 g/s) to 1.0 lb/min (7.56 g/s) per passenger to be made for the same degree of comfort. Subsequent changes to those reported reduced the flow rate to 0.75 lb/min (5.65 g/s) per passenger. These later tests did not use a separate recirculation system for cabin air, which has been common practice to reduce cabin temperature, but utilised jet entrainment to obtain mixing within the cabin allowing use of lower inlet temperatures without passenger discomfort. These tests demonstrate the savings that possibly could be made by the detailed investigation of distribution systems for a particular cabin.

4 ODOUR CONTROL

The magnitude of the odour control problem is subjective and will depend largely upon the amount of smoking, assuming that galleys and toilets are vented directly overboard, and upon the fastidiousness of the passengers.

The humidity of the cabin air and the materials present can also play a significant part in the question of odour control. It has been shown[7] that perception of tobacco, body and cooking odours is decreased with increased humidity and it is suggested that a level of 40-60% relative humidity should be used in air conditioned areas. On the other hand where the odour source is intrinsic to the material, e.g. paint, rubber and upholstery a reduction in relative humidity is beneficial[8] as it reduces the rate of evolution. In nuclear submarines[9] the use of mineral spirit for cleaning and oil based paints were banned due to the odour problems that they created. The materials used in the cabin therefore require some care in selection although information on this aspect is limited and possibly attention paid to the odour absorption properties of materials[10].

Information is lacking on odour control at the volumes per person, air velocities and pressures that exist in aircraft cabins. Accepted American practice for minimum requirements for building air conditioning is given in Refs.7 and 10 from which Fig.6 is reproduced showing the minimum recommended ventilation requirements to avoid obnoxious body and smoking odours. These recommendations are based mainly on experimental work done in the 1930s. Fig.6 indicates a flow rate which varies with the volume per person and a rate of air change as shown in Fig.7 and assumes that the air supply is untreated outside air. Extrapolating these curves to the region of 50 ft^3 (1.415 m^3) per person suggests that a total flow of between 30 and 45 ft^3/min (0.142 and 0.212 m^3/s) per person would be required depending upon the amount of physical activity and smoking, that is 2.4 to 3.7 lb/min (18.1 to 28 g/s).

The most comprehensive U.S. government regulations are those of the 1957 Chicago Ventilating Code. The requirements from this code are shown in Fig.8[10]. This code allows for the recirculation of air with adsorption and temperature control and states that under these conditions on 15% of the total air supply needs to be fresh. A constant rate of change of air of once per 15 minutes is implied. Chapter 7[7] gives the same ratio of fresh air to total air supply for cooling in the summer if dehumidification of the air is used. The ratio is however trebled for winter conditions when the air is being heated and humidified. For a cabin volume of 55 ft^3 (1.56 m^3) per person Fig.8 suggests a flow of the order of 30 ft^3/min (0.152 m^3/s) of which about 5 ft^3/min (0.0024 m^3/s) per person is fresh, assuming that an office ceiling is at 9.0 ft (2.73 m^3). This agrees with the lower curve of Fig.6. These values of total flow are in excess of the values used in current aircraft. Figs.6-8 may not be amenable to extrapolation down to the volume per person current in aircraft cabins with the different distribution. Bedford[11] gives the London County Council requirement supplies to theatres as 17-20 ft^3/min (8.0-9.0 mm^3/s) per person which is comparable to what has been aircraft practice. He suggests that as the fresh air supply per person is increased the efficiency of ventilation is decreased as there is insufficient time for the diffusion of odours to occur and not all the ventilating capacity of the air is used. This is in agreement with American practice shown by Fig.6. In an aircraft cabin the inlet and extraction points are much closer to the person and fresh air can be directed, if required onto the face, by means of punkah louvres at a higher velocity than normally present in a room. This may account for the air supply being below normal practice.

5 TREATMENT OF RECIRCULATED AIR FOR ODOUR REMOVAL

In the preceding discussion it has been assumed that all the air supply is fresh. An alternative system which is used to recirculate the air with purification (removal of odours) and control of the temperature and humidity. About 15% make up fresh air is required. In view of the controlling influence of odours on the flow rate this system may have scope for future development.

The methods of purification are as follows;

(1) Adsorption.
(2) Washing and scrubbing.
(3) Neutralisation and masking.

Activated charcoal is commonly used as an adsorbant, Table 3, Chapter 12[7] gives one odour index for classifying the occupied volume that can be purified per year by 1 lb (0.453 kg) of activated charcoal. An average value quoted for aircraft is 300 ft^3 (8.49 m^3). The weight of charcoal required would be small, but the contact time between the contaminated air and the charcoal determines the efficiency of the process, implying large surface areas or thick filters with high pressure drop. Depending upon the degree of contamination it might not be necessary to pass the whole of the recirculated air through filters. Any pure gases however would not be filtered out. An advantage of this type of purification is that it would absorb any smoke that might result from a fire in the cabin. Regular servicing would be required and performance would vary with time due to clogging.

Odours have also been controlled chemically[12] but again low face velocities are required.

Washing and scrubbing with absorbent liquids can be used where the odorous vapours are soluable or emulsifiable. Absorbents may be water or sprays of hygroscopic liquid, such as a solution of water with lithium chloride;

triethylene glycol etc. These are especially effective if it is desired to dehumidify at the same time as washing. The spray has to be cooler than the air being treated if dehumidification is required. Spray towers with moisture eliminators, sometimes packed with glass wool etc. to increase contact, and venturi scrubbers injecting the absorbent liquid into the venturi throat and discharging the mixture tangentially into a separator are used in building conditioning plants. They can be designed to operate at high air velocities with low pressure loss.

Neutralisation and masking can also be used to eliminate annoyance from odours. These methods depend upon the ascertaining of the composition of the objectionable odour(s) and the supplying of another odour, in the proper concentration, which will counteract or mask. Commercial deodorants are available for body odour, tobacco smoke, cooking smells etc., but the question of adequate metering in an aircraft cabin would cause difficulty with varying passenger loads, amount of smoking etc. Excess concentrations of the deodorants themselves might become objectionable.

If a recirculation system with purification were to be used the method of purification is likely to be a combination of fluid spray and charcoal filters to obtain maximum efficiency and deal with possible smoke contamination.

6 COOLING OF RECIRCULATED AIR

The recirculated air will require to be cooled before it is reintroduced to the cabin and, if dehumidification is used, the spray liquid will need cooling. Depending upon the aircraft there might be sufficient cooling available from the fresh air generation system to achieve the desired temperature of the mixed cabin inlet air in flight.

If there is insufficient cooling available in the fresh air make-up a separate vapour cycle system would be required. Preferably this should be electrically driven so that on the ground it might be powered from an A.P.U. or external ground supply. Limited ground cooling could then be supplied.

The vapour cycle would require a suitable heat sink. At present there are no suitable refrigerants for use with condenser temperatures in excess of 90°C[13]. This precludes ram air for aircraft operating at speeds in excess of about Mach 1.75 in the tropopause. Below this speed ram air could be used, but would offset the gains made by the reduction in fresh air flow and might entail a net weight increase depending on the geometry of the aircraft. In addition fans would be required for inducing flow over the condenser for ground operation.

It is however possible on transport aircraft cruising below Mach 2.0 that the heat capacity of the fuel might be utilised both on the ground and in flight. For prolonged cruise above Mach 2.0 the fuel is likely to reach too high a temperature in the tanks for use in cooling the vapour cycle condenser at the end of flight. The availability of fuel as a heat sink will depend upon the overall heat balance for the aircraft, i.e. the amount of hydraulic and electrical equipment heat being rejected to it. Recirculation will also require fans or compressors with their associated weight and power, which could be large depending upon the amount and method of purification.

7 CABIN PRESSURISATION

The cabin air supplies as well as ventilating the aircraft are used as the means of pressurisation. Therefore there has to be sufficient discharge flow for valves to adequately maintain the cabin pressure. This discharge flow is the air supplied to the cabin less the amount lost by structural leakage and through fixed bleeds such as toilets, galleys, fuel tank pressurisation etc. Structural leakage, which depends upon design and manufacturing tolerances, in present aircraft is of the order of 10-15% of the total flow. If fixed bleeds from toilets and galleys are included this figure would increase by about another 10% and a further 15% in supersonic aircraft where the tyres and undercarriage need cooling. These bleeds therefore account for something of the order of 25% of the total flow before the discharge valves open for a subsonic aircraft and probably about 40% for a supersonic aircraft. Depending upon the limitations of discharge valve size and control range it would appear that a reduction in the flow to maintain pressurisation of the order of 50% could be made for subsonic aircraft.

Over a period of 10 years 67 cases of pressurisation failure[14] have been recorded. Of these the cabin altitude rose to over 14000 ft (4600 m) in 33 cases. The causes of the majority of incidents were associated with discharge valves either due to the malfunctioning of the valve itself or the control system. Four of the cases were due to seal failures and one to a fuselage failure. With reduction of the pressurisation flow and corresponding decrease in the size of discharge valves the severity of any incident due to the malfunctioning of the discharge valves should not be increased. Where however the loss of pressurisation is due to a failure of a door seal, window etc. the final cabin altitude and rate of decrease of pressure will be higher. To cover this possibility, on subsonic aircraft, provision for a flood flow system would be required. This would mean being able to override the cold air unit bypass and the mass flow controller. Some increase in the maximum capacity of the normal cold air unit bypass and the reducing valve might be required at a small increase in weight. Probably no increase in primary heat exchanger capacity would be required as a decrease in thermal performance and increase in pressure drop with the resulting increase in cabin inlet temperature is likely to be acceptable for a short period in an emergency.

For aircraft cruising at altitudes in excess of 40000 ft (12192 m) the problem is more severe due to the higher altitude to which the cabin would rise in the event of a failure. As these aircraft are likely to be of increased performance with high temperatures on the coolant side of the primary heat exchanger and from the engine tapping it would not be possible to bypass the cold air unit for flood flow and it does not seem likely that any reduction in the flow required for pressurisation could be made.

8 EQUIPMENT COOLING

An aircraft flight deck has a separate fresh air supply, this being used for conditioning equipment as well as crew. Where an aircraft carries a lot of equipment some of the passenger cabin air may be required to supplement the flight deck air supply, as in the Concorde where the electronic flight deck load is of the order of 14 kW. Normally equipment conditioning air is not readmitted to the cabin because of the risk of smoke contamination. Therefore the air cannot be considered for use in a recirculation system unless an adequate filtration system is incorporated. The air cooling the equipment is however available to the discharge valves. The same limitations also apply to underfloor equipment and freight holds. To avoid contamination the heat loads from concentrations of electronic equipment could be rejected to the recirculation system or the discharge air by means of a heat exchanger and additional ducting, at the expense of additional weight, employing a closed circuit system.

Providing a closed circuit equipment system would present difficulties in that equipment boxes and connections would require to be adequately sealed.

The choice of a suitable heat transport medium also presents difficulties, air is attractive in that it presents no contamination problem if a leak does occur, but it would however have a relatively high pumping power requirement. The use of liquid im the closed circuit[15] would reduce the requirements for volume and pumping power but would probably increase the weight owing to the liquid in the ducting although this would be of small diameter. Equipment specifically designed for liquid cooling would be required and servicing difficulties would be increased. Mixing of air and liquid cooled equipment would lead to a heavy and inefficient system.

Apart from the development of equipment to operate at higher temperatures, or the redesign of all equipment to be liquid cooled, there does not appear to be any means of reducing equipment cooling requirements. The use of higher equipment operating temperatures could be limited where there are dials or controls which are radiating to the crew or are likely to be touched. Cooling by air from the flight deck and cabin supplies is likely to remain the method for conditioning equipment. The demand of equipment cooling is likely to grow with the increasing sophistication of aircraft.

9 DISCUSSION

Although fresh air requirements per passenger can be greatly reduced from a breathing aspect the other considerations of odour control, pressurisation and equipment cooling mitigate against this, the latter two considerations probably ruling out any reduction on a supersonic aircraft. On subsonic aircraft a reduction of the order of 50% could possibly be made if their cruise altitude is not too high (<40000 ft [12192 m]) and if odour control is satisfactory.

Information on odour control under the conditions that prevail in aircraft cabins is lacking. In tests on a supersonic aircraft cabin[6] a fresh flow of 1.0 lb/min (7.56 g/s) per passenger was used in the final distribution scheme tested without any comments on 'stuffiness' although these had previously expressed at the recommended flow rate per passenger of 1.2 lb/min (9.07 g/s) with a slightly different distribution scheme; this meant a 20% saving in aircraft penalty. The amount of cigarette smoke in these tests may not have been fully representative of a typical passenger cabin. These results however illustrate odour control as well as temperature gradients are influenced by the detail of the distribution system design.

If odour control requires more air than pressurisation and it is desired to reduce the fresh air demands upon the engines a recirculation system with air purification could be used although this is likely to be heavy. The recirculation system on the VC 10, which incorporates a vapour cycle system, weighs about 800 lb (363 kg) for an airflow of 150 lb/min (1.13 kg/s) which is of the order of 5.5 lb/min (0.33 kg per g/s). Since the average fresh air system weight is about 11 lb per lb/min (0.66 kg per g/s) (Fig.9) the saving in weight due to reducing the fresh air flow per passenger by 0.5 lb/min (3.75 g/s) for a 250 seat aircraft would be of the order of 1300 lb (590 kg). If it is assumed that for temperature gradient and odour control the same total flow 1.2 lb/min (9.07 g/s) per person is to be maintained then 0.7 lb/min (5.3 g/s) per passenger will need to be recirculated. Using the VC 10 figures as a basis this would involve a recirculation system weighing about 800-900 lb (363-408 kg) depending upon the amount of integration that can be achieved with other systems and the amount of odour and smoke control equipment required. The net weight saving would therefore be of the order of 400 lb 181.5 kg) and possibly more if the distribution system could be developed to reduce the total air flow requirement, i.e. reducing the total air flow from 1.2 lb/min (9.07 g/s) to 1.0 lb/min (7.56 g/s) per passenger would save a further 230 lb (104 kg).

Reduction in the fresh air flow by 0.5 lb/min (3.78 g/s) will reduce the power demand from the engines by something of the order of 250 kW for a 250 seat aircraft. The power demand of the recirculation circuit with a vapour cycle system would probably be about 20 kW giving a net saving of the order of 200 kW. Extra weight will be involved in converting engine power to electric power for the recirculation circuit equipment, but there will be a reduction in weight if the same thrust from the engine is required as there will be a decrease in engine size. If power is obtained from the engine by air bleed and turbo driven machinery this will also have to be considered in relation to the overall aircraft penalty, when assessing the effects of a reduction in cabin conditioning flow. Assuming that the power load is relatively constant the turbo machine discharge air could be subsequently used for cabin conditioning.

It is possible that in cruise there would be sufficient capacity in the fresh air supply to cool the recirculated air. In the system proposals for the A 300 aircraft for example in the cruise condition over half of the cabin fresh air supply bypasses the cold air unit. If this is possible the weight of the refrigeration equipment in the recirculation system, probably about 650 lb (295 kg) could be saved. However conditioning would not then be available on the ground, except from ground service trucks.

10 CONCLUSIONS

From a purely breathing aspect fresh air supplies could be reduced to the order of 0.25 lb/min (1.89 g s) per passenger. However pressurisation for emergency conditions and equipment cooling requirements will probably prevent any large reduction in total airflow in supersonic aircraft.

Odour control and aircraft 'wetness' will determine the passenger airflow requirement for subsonic aircraft and these need investigation under representative conditions before any firm recommendation can be made. However it seems possible that a reduction of the order of 50% could be made and acceptable odour control obtained by utilising a recirculating system with purification equipment.

Further investigation of distribution systems will be required in order to maintain acceptable temperature gradients in cabins if the total airflow is to be reduced.

Appendix A

ASSUMPTIONS AND METHOD OF CALCULATION

Assumptions

Cabin total pressure	12.3 psia (84.8 kN/m^2)
Cabin temperature	25°C
Initial water concentration	0.0192 lb/lb (g/g)
Oxygen requirement[5]	2.0 lb/man day (10.5 mg/s)
Carbon dioxide evolved[5]	2.25 lb/man day (11.8 mg/s)
Water vapour evolved[5]	2.2 lb/man day (11.52 mg/s)
Supply air consists of 23% oxygen and 77% nitrogen by weight	
Minimum partial pressure oxygen	120 mmHg
Maximum partial pressure carbon dioxide	5 mmHg

Method of calculation

Calculate initial value of gas constant,

$$R_M = R_o W_o + R_N W_N + R_W W_W \qquad \text{(A-1)}$$

where W % of gas or vapour by weight
R gas constant
subscript o oxygen
N nitrogen
W water vapour
M cabin atmosphere.

For assumed volume per passenger, V, obtain amount of mixture required from,

$$W_M = P_T V / R_M T \qquad \text{(A-2)}$$

where P_T cabin total pressure
T cabin temperature °K
W_M weight of mixture required to fill volume per passenger.

For a given supply flow obtain % weight of new atmosphere after a period of 5 minutes allowing for amounts supplied used and evolved obtain new gas constant for the atmosphere and thence the weight, W_M, required to fill the volume being considered to maintain the same total pressure. Calculate new partial pressures of the constituent gases and vapours from

$$P = \frac{W R T}{V}$$

Repeat for required numbers of cycles assuming that total pressure remains constant and excess atmosphere is discharged.

Table 1

CABIN CONDITIONS AFTER 1 HOUR

Cabin volume per passenger		Dry air supply rate		Partial pressure mmHg		Final water content	Final relative humidity	Initial water content
				Oxygen	Carbon dioxide			
ft^3	m^3	lb/min	g/s			lb/lb (g/g)		lb/lb (g/g)
40	1.132	0.1	0.756	122.09	5.49	0.0139	0.594	$5.86\ 10^{-3}$
		0.2	1.51	126.29	3.05	0.0076	0.324	
		0.3	2.27	127.95	2.07	0.0048	0.208	
		0.4	3.02	128.81	1.56	0.00365	0.156	
		0.5	3.78	129.33	1.25	0.00284	0.121	
		1.0	7.56	130.37	0.63	0.00162	0.069	
50	1.415	0.1	0.756	122.58	5.15	0.0137	0.584	"
		0.2	1.51	126.36	2.99	0.0075	0.32	
		0.3	2.27	127.97	2.05	0.0052	0.224	
		0.4	3.02	128.81	1.55	0.0039	0.166	
		0.5	3.78	129.33	1.25	0.00292	0.124	
		1.0	7.56	130.37	0.63	0.00163	0.0695	
75	2.12	0.1	0.756	123.73	4.39	0.0124	0.529	"
		0.2	1.51	126.6	2.81	0.00738	0.314	
		0.3	2.27	128.02	2.00	0.00499	0.213	
		0.4	3.02	128.83	1.54	0.0039	0.166	
		0.5	3.78	129.33	1.24	0.00303	0.129	
		1.0	7.56	130.37	0.63	0.00152	0.0647	
75	2.12	0.1	0.756	123.36	4.39	0.0145	0.616	$1.172\ 10^{-2}$
		0.2	1.51	126.48	2.81	0.008	0.342	
		0.3	2.27	127.98	2.0	0.0052	0.224	
		0.4	3.02	128.81	1.54	0.0039	0.166	
		0.5	3.78	129.33	1.24	0.00313	0.134	
		1.0	7.56	130.37	0.63	0.00152	0.0646	

For a cabin pressure of 12.3 psia (84.8 kN/m^2) and temperature of 25°C the saturation water content is 0.02345 lb/lb (g/g).

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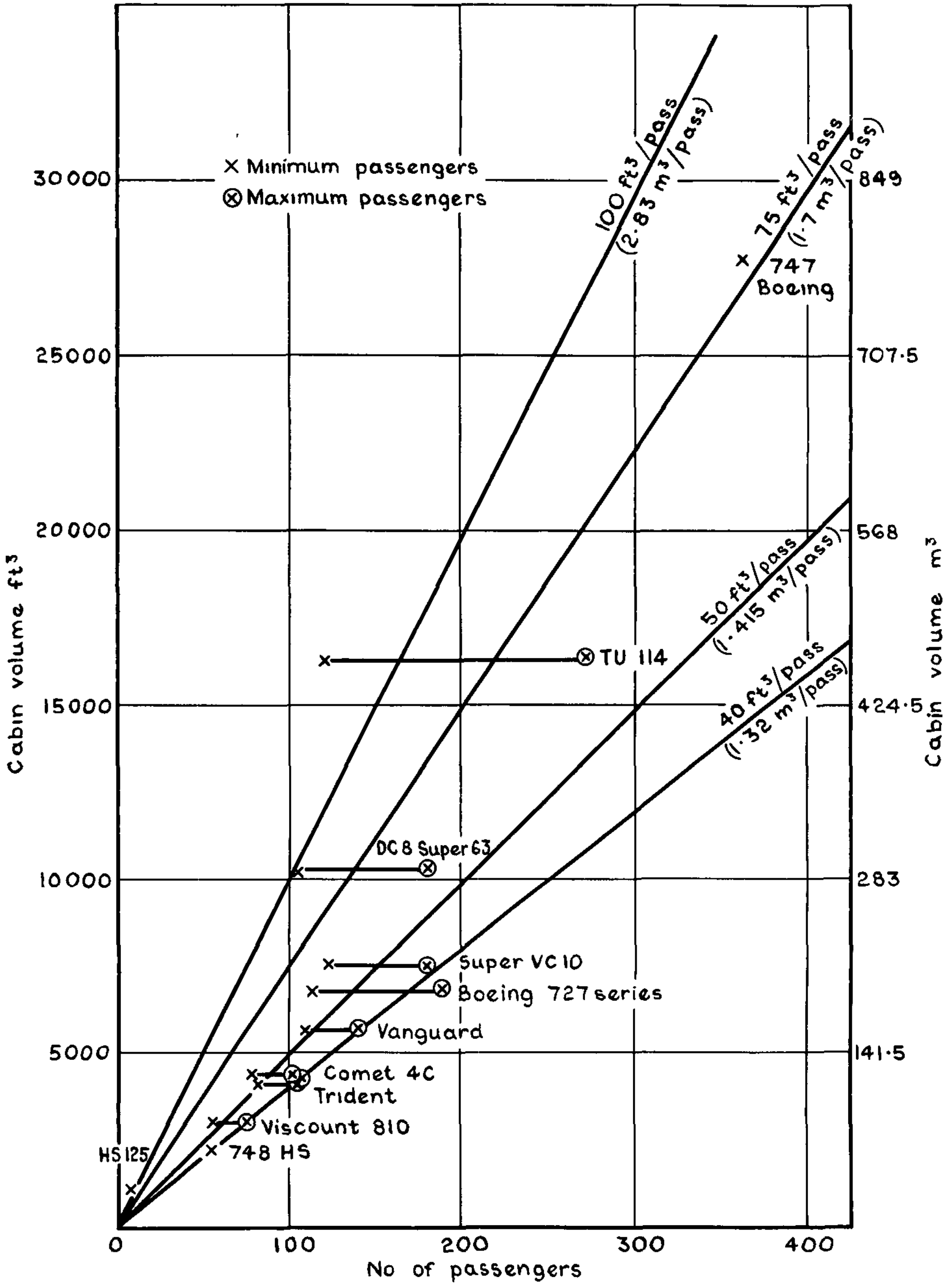


Fig. 1 Current aircraft cabin volumes

Fig. 2

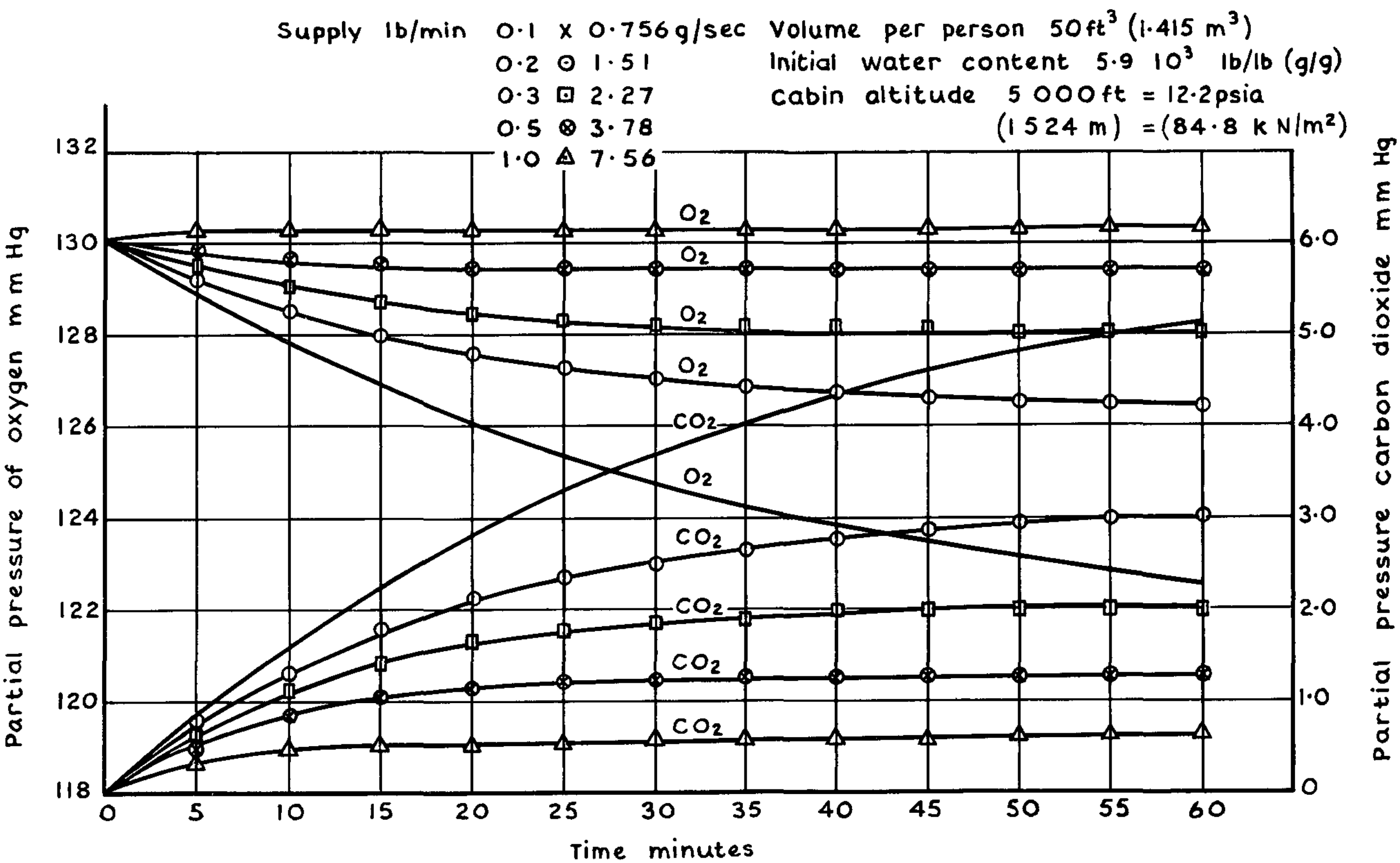


Fig. 2 Typical variation of partial pressure of oxygen and carbon dioxide for different airflow rates

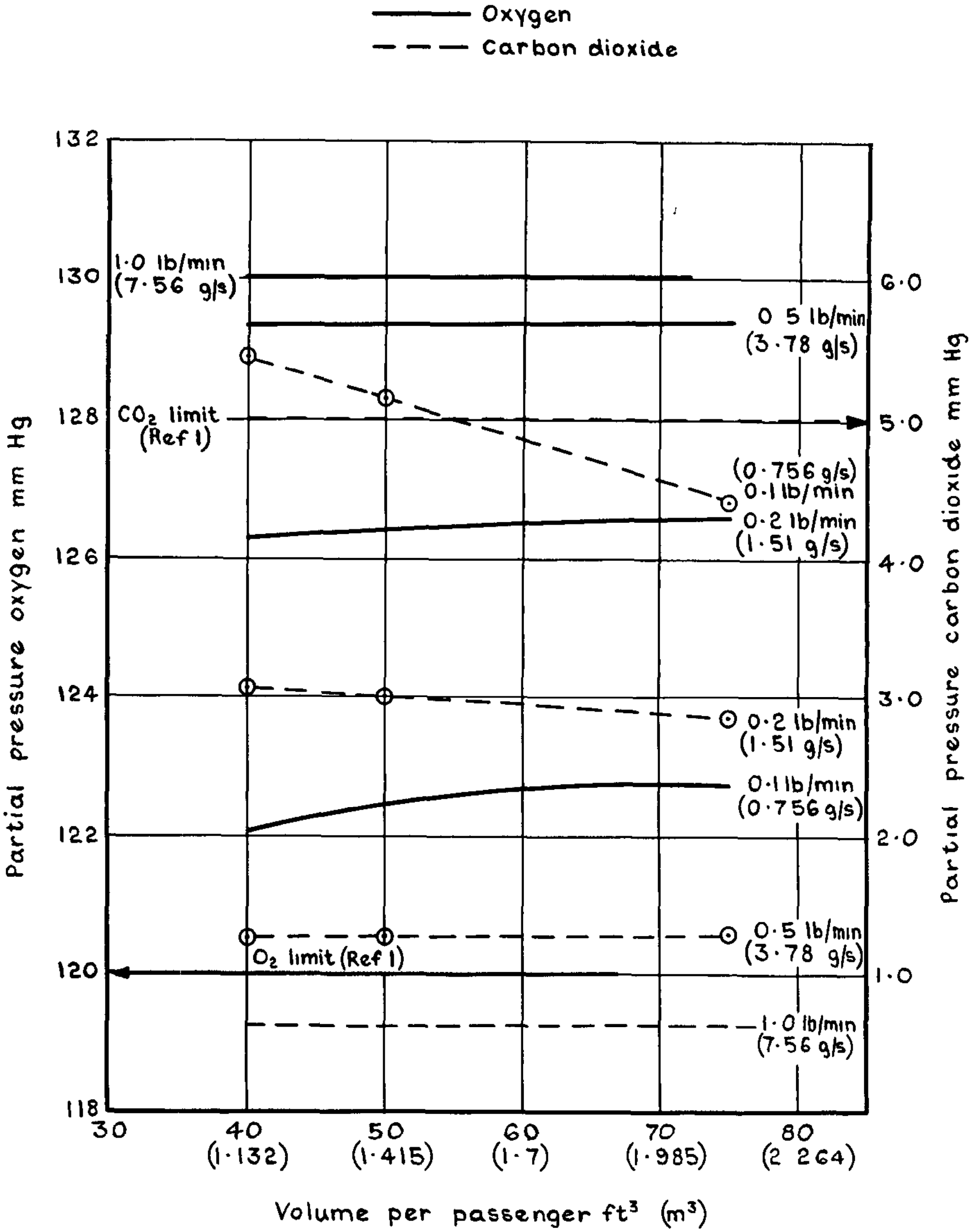
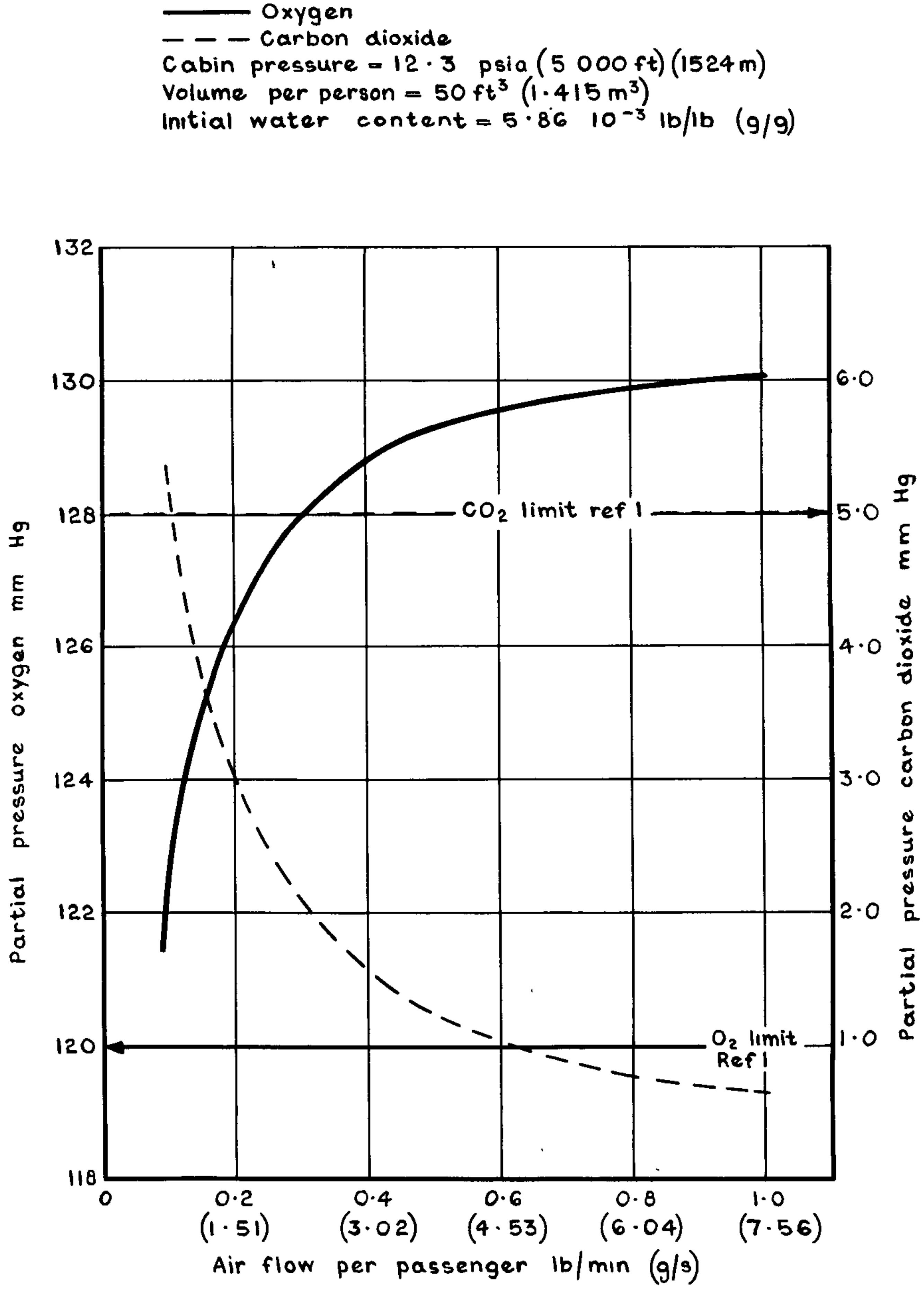


Fig. 3 Effect of cabin volume on cabin air composition after 1 hour

Fig. 4



Cabin pressure = 12·3 psia (5 000 ft) (1524 m)
Volume per person = 50 ft^3 (1·415 m^3)
Initial water content = 5·86 10^{-3} lb/lb (g/g)

Fig. 4 Effect of flow after 1 hour

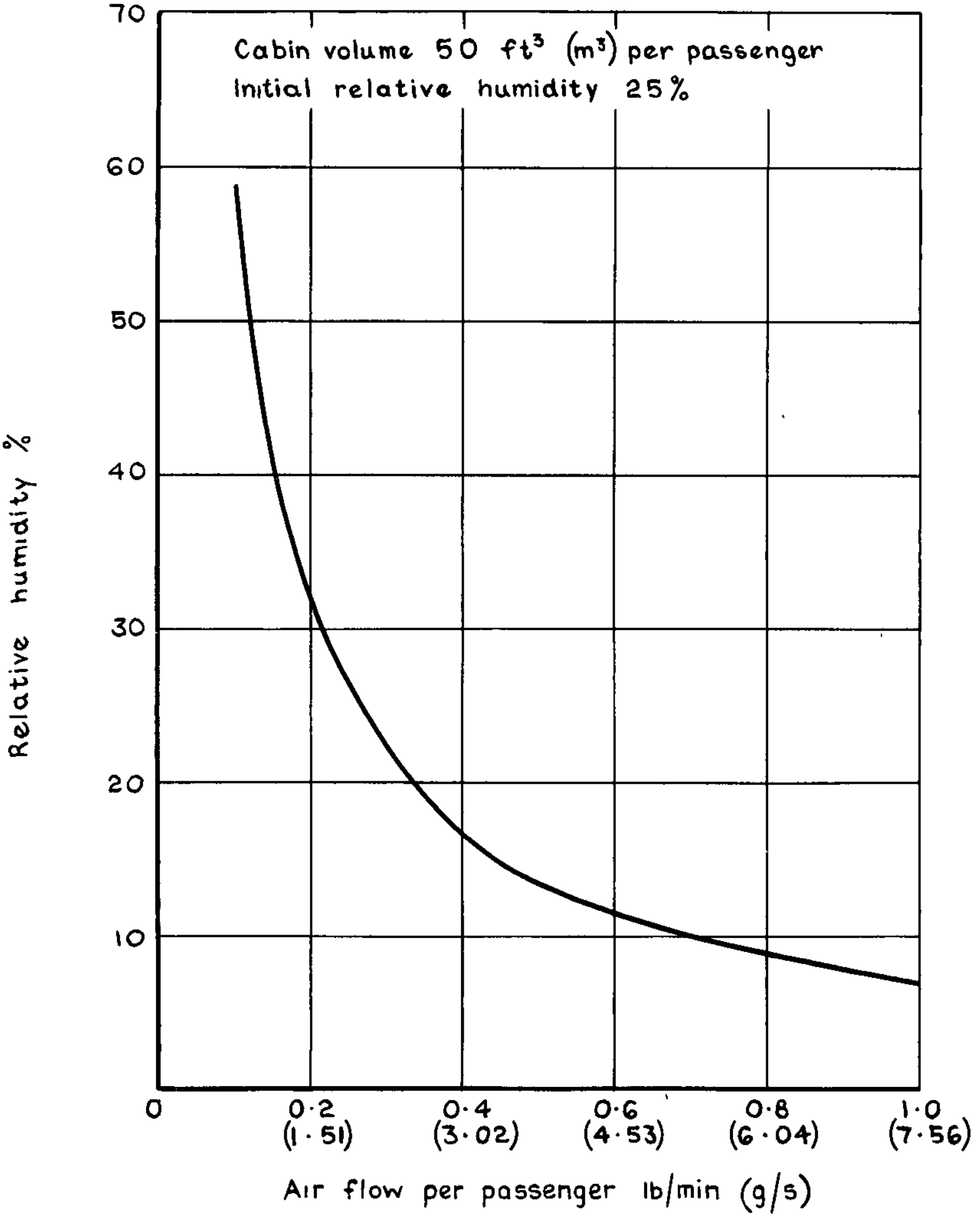


Fig. 5 Cabin relative humidity after 1 hour

Fig.6

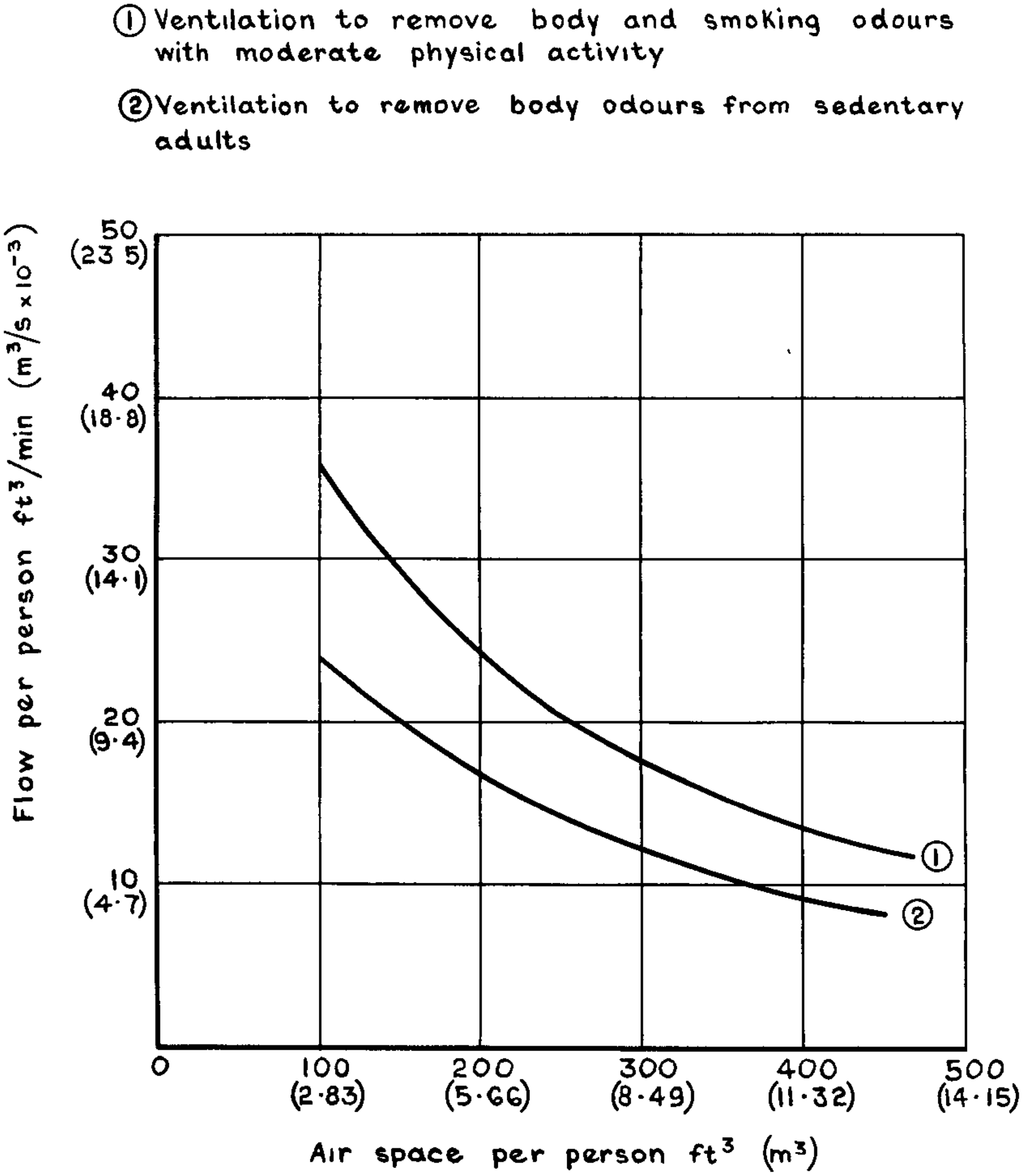


Fig. 6 Flow rate requirements for body odours

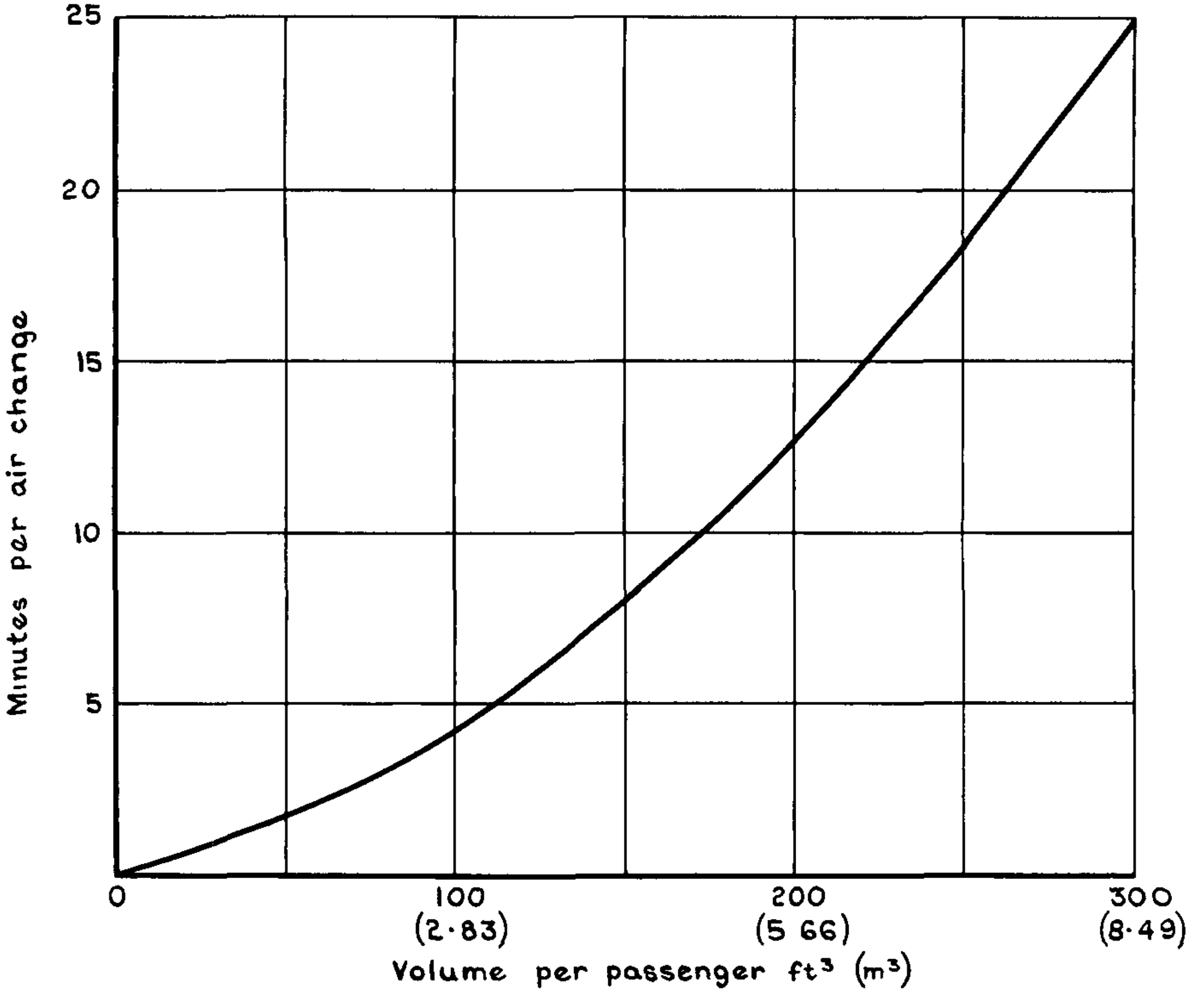


Fig. 7 Minimum ventilation requirements to avoid obnoxious and smoking odours

Fig. 8

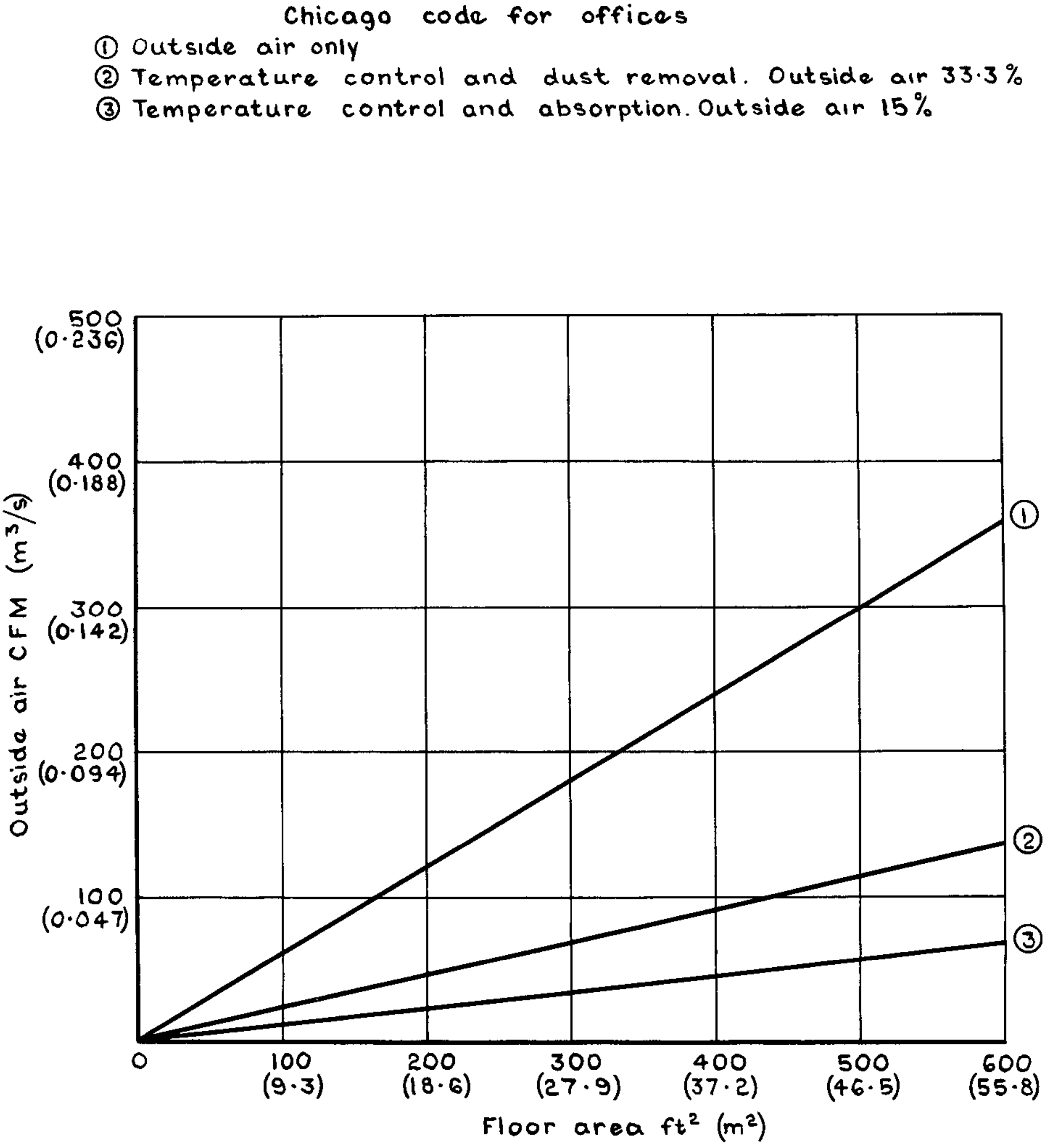


Fig. 8 Chicago code airflow requirements

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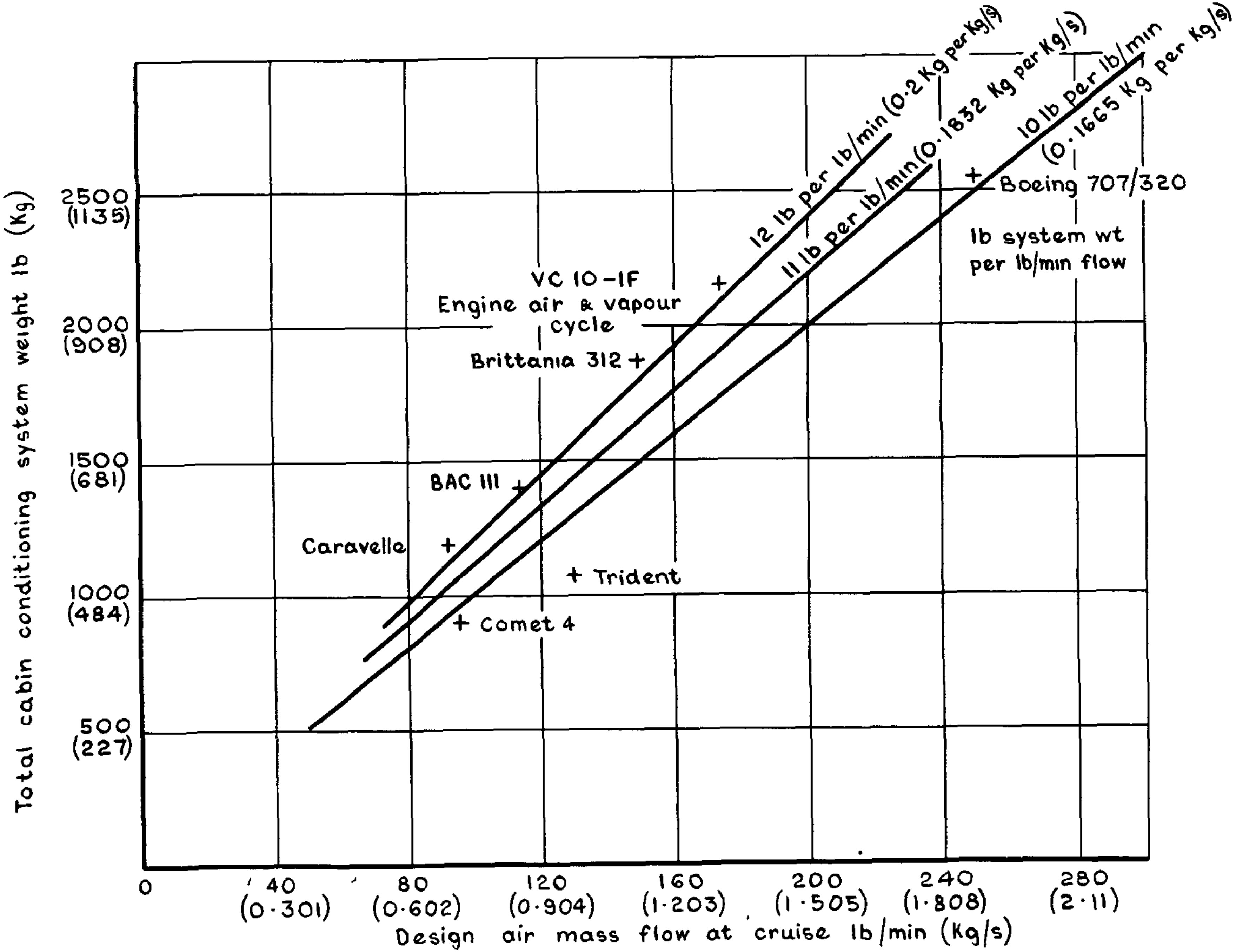

Fig. 9 Air conditioning system weight for design airflow

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AIRFLOW RATE REQUIREMENTS IN PASSENGER AIRCRAFT

Airflow requirements for cabins of passenger transport aircraft are considered from the aspects of breathing, temperature control, odour control, pressurisation and equipment cooling. In supersonic aircraft the consequences of a pressurisation failure and the requirements of equipment cooling are likely to prevent much reduction in airflow below current figures. In subsonic aircraft the airflow could be reduced for pressurisation but is likely to be dictated by odour control on which information is lacking under representative conditions. The minimum engine air bleed rate would occur for a system which recirculates and purifies a proportion of the cabin air. Development of cabin air distribution systems would be required if airflow is to be reduced.

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