DISINSECTIZATION OF AIRCRAFT

Study made in connexion with the Revision of International Conventions *

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When health authorities inspect aircraft arriving from airfields situated in tropical or subtropical areas, it frequently occurs that a few live insects are discovered on board, even though disinsectization operations, as laid down in Articles 38 and 54 of the International Sanitary Convention for Aerial Navigation of 12 April 1933, and modified by the International Sanitary Convention for Aerial Navigation, 1944, were apparently carried out before landing.

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It follows that the accidental introduction by aircraft of insect vectors of tropical diseases into unaffected areas is always possible, although such a problem is not a particularly serious one. Certain countries are still apprehensive, not without reason, of such a situation developing, and have arranged for their health authorities to carry out a systematic and complementary disinsectization of aircraft on their landing, in accordance with Articles 47, 51 and 54 of the Convention cited above. At the same time, the lack of a uniform and universally accepted method of aircraft disinsectization has resulted in the application by health authorities of national methods, which often vary from one State to another. This fluctuating state of affairs is becoming a hindrance, sometimes a serious one, to the normal development of international air traffic, and, moreover, may possibly be a factor in the partial inadequacy of disinsectization operations. For these reasons, the Expert Committee on Quarantine of the Interim Commission of the World Health Organization \(^{88}\) considered it advisable to standardize not only the insecticide, but also the method for efficient disinsectization of aircraft.

Such standardization is most desirable, as it will greatly simplify the application of sanitary control of air traffic, and at the same time will make it possible to prevent the accidental introduction of all kinds of insect parasites and disease vectors into regions in which such parasites are either not indigenous or have been eradicated.

The purpose of this study is, therefore, to give an account of the epidemiological problems created by the penetration of insects into aircraft; to determine the kinds of insecticides which may be used, taking into account the conditions peculiar to air traffic; and, finally, to lay down the disinsectization methods corresponding to the technical requirements for either the type of construction or the conditions of service of the various types of aircraft at present in use.

1. PROBLEMS CREATED BY THE PENETRATION OF INSECTS INTO, AND THEIR TRANSPORT BY, AIRCRAFT

The possibility of transporting live arthropods in aircraft has been amply verified by past experience. When they manage to penetrate into cabins, freight compartments, or any other part of the aircraft which is sheltered from the wind, insects withstand the longest trips without apparent damage, and resist altitude, lowering of barometric pressure, and cold.

Hicks & Diwan Chand \(^{24}\) left cages containing mosquitoes in charge of pilots flying the Karachi-Amsterdam route. Female *Stegomyia* were still alive on arriving at Amsterdam, and on the return trip a certain number was found alive at stops at Cairo and Baghdad and even on arrival at Karachi. Sicé, Sautet & Ethes \(^{66}\) received *Anopheles gambiae* sent by plane
to Marseilles from the French Sudan. These mosquitos laid eggs which were able to hatch in artificial breeding-places at the ordinary seasonal temperature (June). They showed normal development, without particular precautions being taken, and on becoming adults were able to reproduce.

According to McFarland, Dunnahoo, in the course of experiments in 1941, placed screen-cages containing Aedes aegypti in various parts of an aircraft flying the Miami-Balboa route. The air current at wing level did not affect the insects. Only those cages which had been placed at wheel level were found empty, violent currents having probably destroyed and blown away the mosquitos. According to experiments carried out by Hicks & Diwan Chand, rapid changes in altitude do not diminish their vitality.

The low temperatures found at altitudes of 3,500 to 4,800 metres are not in the least lethal to insects. Mosquitos placed experimentally in a room cooled to $-45^\circ$ C. recovered their vitality when brought into a warmer room. On the other hand, they are severely affected by contact with hot, dry surfaces. They are also sensitive to hygrometric changes in the air, dryness soon killing them.

Vibrations of the various parts of the structure of aircraft during flight are even more decisive. Contact with rapidly vibrating surfaces immobilizes mosquitos and apparently deprives them of all activity. However, this factor is less important in the cabins of modern aircraft as designers have made a great effort to reduce vibrations so as to improve the comfort of passengers. During experiments carried out in flight by the US Public Health Service, a mosquito was discovered in the act of biting a passenger.

It will thus be seen that systematic inspections of aircraft reveal the presence of various kinds of insects. These insects may penetrate into the cabin or freight compartments either before departure, during checking operations or loading, or during stops. They may leave the aeroplane which has harboured them at any stop, as soon as the doors, hatches and freight-compartment panels are opened. A certain number of phototropic insects will even be attracted by the lights of aerodromes during night stops, especially as it is customary to extinguish lights on board when petrol tanks are being filled.

1.1 Insect Infestation of Aircraft

The number of insects which an aircraft may contain varies considerably according to the districts where the aeroplane has landed, its tonnage and its state of upkeep. Aircraft which remain for a few days in tropical countries, either parked or for overhaul, may become uninhabitable. Klots mentions the case of a single B-29 bomber, in which the two lateral blisters of the fire-control compartment had been thoroughly sprayed with insecticide, destroying more than 7,500 mosquitos. Mosquitos were so numerous
in certain aircraft parked on the same airfield that flights had sometimes to be delayed or even cancelled. Crew members had to be exempted from duty because of the number of mosquito bites which they had received.\textsuperscript{a}

In practice, on commercial lines, the regular upkeep of aircraft generally reduces infestation to a small number of specimens. Since the inauguration of the transpacific airline in 1936, a close entomological supervision has been carried out of aircraft on airfields in Pearl City (Honolulu), Canton Island (Phoenix Islands) and Midway, in order to prevent the introduction by air of human, veterinary, and agricultural parasites into Hawaiian territory. The following data given by Pemberton\textsuperscript{56} indicate the relative degree of infestation of aircraft during this period. From March 1936 to December 1941, 301 aeroplanes arriving in Hawaii from Hongkong or Manila, via Midway, or from New Zealand, via Canton Island, were inspected. Although they had been sprayed with insecticide immediately before taking off and shortly before arriving in Hawaii, 10,081 mosquitos, of which 2,067 were still alive, were discovered. Among the insects collected were 4 living specimens of \textit{Culex fatigans} and 207 dead mosquitos, comprising \textit{Anopheles litoralis}, \textit{Aëdes vexans}, \textit{Aëdes vigila} and \textit{Culex sittens}. During the same period, only 1,367 insects, of which 137 were alive, were discovered in the 321 aeroplanes arriving in Honolulu from California.

\begin{table}
\centering
\caption{Mosquito Infestation of Transport Aeroplanes at Miami Airport, 1939-1944}
\begin{tabular}{|c|c|c|c|c|}
\hline
Fiscal year* & Number of aircraft & Total number of mosquitos found & Number of mosquitos per 100 aircraft \\
& & dead & alive & \\
\hline
1939 & 1,610 & 26 & 3 & 1.6 & 0.2 \\
1940 & 1,995 & 37 & 8 & 1.9 & 0.4 \\
1941 & 2,305 & 47 & 9 & 2.0 & 0.4 \\
1942 & 4,552 & 245 & 24 & 5.4 & 0.5 \\
1943 & 6,945 & 449 & 43 & 6.5 & 0.6 \\
1944 & 9,287 & 1,371 & 81 & 14.8 & 0.9 \\
\hline
\end{tabular}
\end{table}

They included 88 mosquitos, amongst which was found a living female of \textit{Anopheles pseudopunctipennis} and one specimen of \textit{Culiseta (Theobaldia) incidens}. It should be noted that 22 of the live insects captured in aircraft during this period were unknown before in Hawaii.

Statistics published by the US Public Health Service summarizing the number of mosquitos collected at Miami airport during the fiscal years 1939 to 1944 (see table I) give a clear indication of the progressive increase in the number of insects in civilian and military transport aircraft, this increase probably being connected with the increase in tonnage.

\textsuperscript{a} Most of these mosquitos were \textit{Psorophora confinis}, \textit{Psorophora ciliata}, \textit{Anopheles crucians}, there being also a few \textit{Anopheles quadrimaculatus}. 
During the fiscal year 1946, among 21,830 aeroplanes which landed on four important airfields of the United States — Miami (Florida), San Juan (Puerto Rico), Honolulu (Hawaii), and Brownsville (Texas) — 30.5% transported insects, with an average of 300 insects per 100 infested aeroplanes, and 4% transported mosquitos, with an average of 160 mosquitos per 100 aeroplanes. But according to Miller, Burgess & Carpenter, the number of mosquitos generally detected in aircraft is estimated at only 10%.

1.2 Classification of Insects found in Aircraft

A general census of insects which were collected, alive or dead, in aircraft, shows that they can belong to the most varied species.

Whitfield took the trouble to draw up a list of them in 1939, adding to his personal observations the statistical results obtained from 1932 onwards by Griffitts & Griffitts, Michel, Richards, Ross, Symes, Trolli, and Welch, following the inspection of aircraft arriving on aerodromes in Miami, Durban, Khartoum, the Belgian Congo and Kenya. In this way, he arrived at a total of 3,761 insects belonging to 225 different species, some of which are of definite epidemiological importance as they are the usual vectors of tropical diseases. In Whitfield’s statistics, these are represented, in particular, by 381 specimens belonging to 28 species, including the following:

*Aëdes aegypti*
*Aëdes luteocephalus*
*Aëdes simpsoni*
*Aëdes taeniorhynchus*
*Mansonia africana*

which are capable of transmitting yellow fever, and

*Anopheles gambiae*
*Anopheles funestus*
*Anopheles albimanus*
*Anopheles pharoensis*
*Anopheles pseudopunctipennis*

which are malaria vectors.

Others relate to animal diseases:

*Aëdes sollicitans* and *Aëdes taeniorhynchus* (equine encephalomyelitis)
*Stomoxys calcitrans* (equine infectious anaemia)
*Aëdes aegypti* (canine filariasis)
*Glossina palpalis* (trypanosomiases)

Regarding agricultural parasites, Pemberton, found, in a clipper arriving in Hawaii from the Far East, fragments of a specimen of *Leucocepholis irrorata*, a Philippine parasite of sugar cane. In 1934, an inspection
of 3,051 aeroplanes landing on various airfields in the USA, carried out by agents of the Bureau of Entomology and Plant Quarantine, US Department of Agriculture, resulted in the seizure of dangerous agricultural freight in 923 cases. Ten years later, the same services, operating in 27 airports and inspecting 21,577 aeroplanes, discovered agricultural merchandise containing, or suspected of containing, parasites, in 3,031 of these aeroplanes. Among the insects captured were:

- the Mediterranean fruitfly,
- the Mexican fruitfly,
- two varieties of *Anastrepha* (one probably being the citrus black fly),
- the East Indian bean-pod borer.

Oakley, summarizing the reports of entomological inspections of six airports in southern and eastern United States, observed that 334 species of insects, unknown until that time in American territory, were discovered in aircraft arriving from abroad; of these, 177 are considered to be parasites in their countries of origin.

It will thus be understood that, following similar observations made during the inspection of aeroplanes arriving at Shannon (Ireland), O'Rourke wonders whether aeroplanes have not become more dangerous than ships as a means of transporting insects from one region to another. To substantiate this remark, he points out that:

1.3 Problem of Yellow Fever

The preceding remarks partly justify the disquiet which has been shown on many occasions by public-health experts on the possibility of yellow fever spreading to regions other than those in which it is endemic, as a result of the expansion of air transport serving central Africa and South America.

Indeed, passengers arriving from endemic yellow-fever areas no longer constitute the greatest danger, as the general application of yellow-fever vaccination, which has in practice become compulsory for persons arriving in a yellow-fever endemic area, greatly reduces the risk of transferring a virus carrier by air to an immune region, in which biological and climatic conditions favour the introduction of the disease.
The sole remaining dangers are the accidental introduction by air of infected living female *Stegomyia*, or the accidental infection of a non-vaccinated passenger by a live, infected *Stegomyia*, picked up by the aeroplane during a former trip in an endemic yellow-fever area.

In view of the combination of conditions required for their realization, these possibilities appear rather limited. Griffitts, and Whitfield, are of the opinion that *Aedes aegypti* (*Stegomyia fasciata*), the principal agent in the interhuman transmission of yellow fever, is a house-haunting mosquito which rarely escapes from buildings and which has little tendency to leave aircraft once it has managed to penetrate them. It should be mentioned, moreover, that *Aedes aegypti* has so far rarely been found during inspections of aircraft. Whitfield has encountered only two cases, to which should be added one specimen found at Miami, and another discovered in Natal in 1943 and mentioned in the list of insects identified by Carneiro de Mendonça & Cerqueira.

However, until the States concerned succeed in effectively applying the recommendations of the International Sanitary Convention for Aerial Navigation 1933/1944, which requires contracting parties to render and maintain free of yellow-fever insect vectors

(a) airfields and their surroundings in endemic yellow-fever areas,

(b) airfields outside endemic areas, but where there is a risk of introducing the disease,

it will still be necessary, as an immediate prophylactic measure, to carry out a systematic disinsectization of aircraft on each airfield situated in an endemic yellow-fever area, and particularly when leaving the last aerodrome in such an area (Article 38 of the Convention).

It should be noted that those who framed the International Sanitary Convention wished to increase the efficacy of this measure by stipulating that a further disinsectization of aeroplanes arriving from an endemic yellow-fever area should be carried out at the first airport situated in an area free from the disease, but where conditions might be favourable to its development (Article 47, paragraph 1b).

1.4 Problem of Malaria

The remarks on yellow fever are applicable also to malaria prophylaxis. In 1939, Whitfield had thought that the prevalence of this disease throughout the world justified the belief that the increase in air transport would not greatly change the situation. The infestation of an area such as Brazil, however, by *Anopheles gambiae*, which was probably introduced in 1930 or 1931 by a ship arriving from the West Coast of Africa, stresses the importance of sanitary surveillance being carried out in the case of aircraft taking off or landing in endemic malarial areas.
It should be emphasized that, since the conclusion of the campaign undertaken in Brazil for the eradication of *Anopheles gambiae*, the dangers of re-infestation in this area have once again appeared, and the role played by aircraft has been indisputably proved.

According to da Silva, more than 90% of aircraft arriving in Brazil from West Africa between 4 October 1941 and 31 March 1942 harboured insects, among which the usual malarial vectors were identified. According to Farrell, 182 *Anopheles gambiae* were detected between February and October 1942 in aircraft arriving from Africa, 4 of the insects being alive, in spite of the spraying of insecticides in the aircraft before landing. According to statistics compiled by Carneiro de Mendonça & Cerqueira, summarizing the results of inspections carried out in airports at Bélem, Fortaleza, Natal and Recife from January 1942 to December 1945, 7,547 arthropods were collected in the 10,060 aeroplanes inspected, and of these 1,070 were still alive. In 152 of these aeroplanes, 352 *Anopheles gambiae* were found.

**1.5 Problem of Other Diseases**

The importance of problems arising from the possible presence of infected mosquitos in aircraft is not limited to the dangers of importing malaria and yellow fever. There are many other diseases, caused either by viruses or bacteria, which are also transmitted by insects already found in aircraft.

Dengue fever, which is transmitted by *Stegomyia*, at one time led to the adoption of maritime sanitary measures because of the spread of the disease in the eastern Mediterranean. Carneiro de Mendonça & Cerqueira mention four specimens of *Glossina palpalis* found in seaplanes arriving in Brazil from Africa. Dampf has reasserted the possibility of spreading onchocerciasis by air, starting from foci in tropical Africa, and, with regard to this disease, Richards has mentioned the discovery in 1936 of 9 flies of the genus *Simulium* in aeroplanes arriving in Khartoum. Eighteen of these flies were also included in a list of insects collected in aircraft in Brazil and identified by Carneiro de Mendonça & Cerqueira.

Du Toit mentions, among the veterinary diseases liable to be spread by insects transported in aircraft, East African coast fever (*Theileria parva*), anaplasmosis and Nairobi disease. The principal vector in each case is a tick, and an infected insect is able to live nearly a year without food.

**1.6 Need for Disinsectization of Aircraft**

These facts justify close adherence by the health authorities concerned to the provisions of Article 54, paragraph 3, of the International Sanitary Convention for Aerial Navigation, 1933/1944, which states:

"In view of the special risk of conveying insect vectors of malaria and other diseases by aircraft on international flight, all such aircraft leaving affected areas will be dis-
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insected. Notwithstanding the terms of Article 54 of the 1933 Convention as hereby amended, further disinsectization of the aircraft on or before arrival may be required if there is reason to suspect the importation of insect vectors."

In practice, the disinsectization operations carried out may be only partial and relate solely to the eradication of certain insects which are particularly dangerous, such as mosquitos. They may also be general with a view to ridding an aeroplane or its cargo of all vermin which may be sheltering there. These two methods correspond to different health problems and require different technical solutions.

Agricultural pests, in particular, give rise to complex problems. Measures required for the eradication from aircraft of insect vectors of human or animal diseases do not, in certain cases, suffice when applied to agricultural parasites. Special prophylactic measures may be required, the definition of which is principally the duty of plant-protection services.

In this study we will, therefore, examine only control measures against mosquitos and winged insects, for this is the most important problem for aerial navigation and requires a speedy solution.

2. INSECTICIDES SUITABLE FOR USE

Because of the special difficulties of air transport, the destruction of mosquitos in aircraft must be a technically simple operation, which can be repeated easily, either in flight or on the ground, in such a way that the time and method of carrying out these operations do not add substantially to the difficulties of air travel. In order to be efficacious, the destruction of mosquitos should be able to be carried out after the loading of freight and in the presence of the crew and passengers, whose clothes and personal luggage might be harbouring a few mosquitos.

For these reasons, the insecticides to be used should comply with a certain number of requirements:

(a) Complete lack of fire risk, thus permitting application while the motors are running, either on the ground or during flight;
(b) marked insecticidal activity and rapid action, limiting the stoppage of ventilation in the aircraft to a minimum;
(c) great diffusibility, thereby favouring penetration into all parts of an enclosed space;
(d) non-toxicity to man and absence of contaminating action on food substances;
(e) ease of application and simple equipment, making it unnecessary to have specialized personnel.
At first, fumigation with toxic gases was tried. Certain quarantine stations used hydrocyanic acid gas for the disinsectization of aircraft during night stops (Griffitts,\(^{22}\) Symes \(^{74},^{75}\)). But the necessity of having a somewhat cumbersome apparatus and specialized personnel, of being obliged to make passengers leave the aeroplane and of completing the operation by a prolonged ventilation, thus permitting the entry of further insects, soon led to the abandonment of this procedure, despite its real effectiveness.\(^{c}\)

Such was also the case with carboxide, a gaseous mixture composed of one part ethylene oxide and nine parts compressed carbon dioxide in a steel cylinder, its action being much too slow, sometimes incomplete, and requiring heavy concentrations of gas which are irritating to the respiratory tract (Williams & Dreessen \(^{85}\)).

Pyrethrum extracts dissolved in a diffusible excipient gave the most satisfactory results until the appearance of preparations containing DDT, either associated with pyrethrin or not.

2.1 Insecticides containing Pyrethrins

Sinton & Wats,\(^{68}\) investigating in 1935 the general principles governing the effectiveness of insecticides, came to the conclusion that the best insecticide for spraying purposes is pyrethrum extract, which is highly toxic to insects, especially mosquitos, while being innocuous for man.

Pyrethrum powder, the active principles of which are pyrethrin I (an ester of pyrethrolone and of monocarboxylic chrysanthemum acid) and pyrethrin II (an ester of pyrethrolone and of dicarboxylic chrysanthemum acid) has marked toxic properties for a large number of insects. Pyrethrins seem to be neuromuscular poisons acting on the central nervous system, causing the death of insects sensitive to them by muscular paralysis and motor inco-ordination, following a convulsive phase. Insecticidal action is not uniform, however, and varies according to the species of insect: some are immediately overcome, others are slowly intoxicated, while some are unaffected by the insecticide.

The optimum temperature for the action of pyrethrins on insects seems to be approximately \(29^\circ\) C. (\(35^\circ\) C. in experiments carried out by Sinton & Wats \(^{68}\)). Insecticidal action then decreases roughly in proportion to the drop in temperature. Optimum relative humidity is below 40\%, while a humidity of 75\% reduces the effectiveness of the insecticide.

Two types of pyrethrum solution are sold on the market: a standard pyrethrum extract No. 20, containing 2\%, by weight, of pyrethrins I and II, and a concentrated pyrethrum extract with a 20\% pyrethrin content. The

\(^{c}\) Disinsectization with hydrocyanic acid gas was again used in France in 1945, as a prophylactic measure against exanthematic typhus, during the repatriation of prisoners and deportees. In all, 1,033 aircraft were treated in this way without incident. This method can still be recommended for the disinsectization of freight suspected of containing agricultural parasites.
latter is free from the resinous substances usually found in the standard extract No. 20. Until about 1936, commercial products such as Flit or Shelltox were frequently used for the eradication of mosquitoes from aircraft. Investigations made by Hicks & Diwan Chand,24 Williams & Dreessen,85 and other authors showed the relative inefficacy of these products and resulted in the search for more active substances, which could be sprayed so as to form a highly diffusible cloud of sufficient density to ensure complete lethal action.

Nijkamp & Swellengrebel 52 have suggested the following formula:

Concentrated pyrethrum extract (20% pyrethrin) . . . . 5 g.
Sassafras oil ........................................... 5 ml.
Methyl salicylate d .................................. 20 ml.
Kerosene e ............................................... 1,000 ml.

The solution is sprayed at a rate of 5 ml. per cubic metre, or approximately 140 ml. per 1,000 cubic feet, f corresponding to a dispersal of approximately 0.14 g. pyrethrin.

Sinton & Wats 68 used Pyrocide 20g experimentally in a 5% solution in kerosene. According to Hicks & Diwan Chand, 55 fine spraying of 60 ml. of this mixture in an enclosed space of 1,000 cubic feet, corresponding to a dispersal of approximately 0.05 g. pyrethrin, kills all mosquitoes after 5 minutes’ exposure to the insecticide.

In order to counteract the possible inflammability of petroleum vapours, Williams & Dreessen 86 suggested the substitution or association of other agents for spraying the insecticide, and recommended pyrethrin-kerosene solution with carbon tetrachloride. With this principle in mind, Symes 76 proposed the Griffiths and Michel formula:

Stafford Allen concentrated pyrethrum extract . . . . 1 part
Kerosene ............................................... 16 parts
Carbon tetrachloride ................................. 68 parts

An enclosed space of 1,000 cubic feet is completely rid of mosquitoes in 5 to 10 minutes by spraying a dose of 20-25 ml. in the form of a well-atomized, stable cloud. For such a small quantity, the presence of kerosene carries with it no danger of fire.

All these formulae, with considerable variation in pyrethrin content, have in their time given satisfactory results; but to obtain a standard insecticidal compound, it is essential to define the minimum lethal dose of the basic active principle, that is, the amount of pyrethrin which, in

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d Because of its persistent and unpleasant odour, methyl salicylate need not be used, as its only purpose is to verify whether the insecticide has been effectively sprayed.

e Kerosene is ordinary white lamp-oil, which is a petroleum fraction with boiling-point between 130° and 180° C. It should contain few volatile fractions, as their presence hinders the formation of a stable insecticidal cloud.

f 1,000 cubic feet is equal to about 28 cubic metres.

g Pyrocide 20 is a standard commercial extract containing 2 g. pyrethrin per 100 ml. Pyrocide 40, more highly concentrated, contains 4.3 g. pyrethrin per 100 ml.
an enclosed space of given volume, effects the complete destruction of mosquitos.

2.1.1 Minimum lethal dose of pyrethrin

Williams & Dreessen\(^8\) had estimated that from 0.04 g. to 0.08 g. pyrethrin is required to kill all mosquitos in an enclosed space of 1,000 cubic feet. Hicks & Diwan Chand,\(^2\) while carrying out experiments on *Aedes aegypti*, obtained satisfactory results with a dose of 0.05 g., and at that time it was laid down that such an amount would be used for disinsectization purposes at Cairo and Alexandria for aircraft calling there en route for India from endemic yellow-fever areas.

The US Public Health Service requires the use of greater quantities.\(^7\) Disinsectization carried out by mechanical sprays must disperse, per 1,000 cubic feet, 8 ml. of standard pyrethrum extract with a 2% pyrethrin content, or approximately 0.13 g. pyrethrin. This dose is reduced to 0.1 g. when spraying is carried out either by means of compressed-air sprayers or of an aerosol.

The experts at the British West Indies Quarantine Conference (Port of Spain, 1943) also recommended the use of 8 ml. of standard pyrethrum extract with a 2% pyrethrin content, or approximately 0.13 g. pyrethrin for mosquito destruction in a space of 1,000 cubic feet, with a minimum exposure of 5 minutes to insecticidal action.\(^8\)

During experimental checking operations carried out at Kisumu (Kenya) for the eradication of mosquitos in British Overseas Airways Corporation seaplanes, Garnham\(^2\) sprayed 3.8 g. of oily Kenya pyrethrum extract (approximately 0.08 g. pyrethrin per 1,000 cubic feet, at a temperature of 24° to 26° C. and at a relative humidity of approximately 50%), and noted that all mosquitos (*Aedes aegypti* and *Aedes taeniorhynchus*) in sprayed parts of the aircraft were paralysed after 5 minutes’ exposure to the insecticide and were dead after 15 hours. A dose of 4.6 g. per 1,000 cubic feet (approximately 0.09 g. pyrethrin) made it possible to reach mosquitos in certain well-protected places.

It would thus seem that the minimum dose for the eradication of mosquitos from aircraft can be set, with an adequate safety margin, at 0.1 g. pyrethrin per 1,000 cubic feet of enclosed space requiring treatment. It should be understood by this definition that the minimum lethal dose recommended should be sprayed by suitable means, which will be discussed later.

For such a dose, the minimum period of exposure to the insecticide can be set at 5 minutes.

### 2.2 Rotenone

Rotenone, or tubatoxin, an extract of the root of *Derris elliptica*, is also very toxic to a number of insects. It brings about paralysis of the respi-
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ratory nerve centres, and is quick-acting for cockroaches, flies, moths and mosquitos. At the present time, it is sold commercially as an insecticide containing rotenone and pyrethrin (MCP insecticide). However, because of its high cost, the state of available stocks and the fact that it is sold as a spray solution, it is not possible at present to foresee its general use as a "routine" insecticide in aircraft.

2.3 Contact Insecticides: DDT

One of the most important contributions of the second World War to public health and general prophylaxis has been the large-scale study and application of the properties of the so-called contact insecticides.

Included in this group are a certain number of substances, differing chemically, which produce the same special physiological effect on insects. These substances, which are very soluble in lipids, spread easily in the chitin forming the entire outer covering of arthropods. The slightest contact of the extremities of the insects' legs with one of these substances suffices to ensure its penetration and dispersion throughout the organism, and death follows by progressive paralysis as soon as the insecticide reaches the nerve centres.

Among contact insecticides only one, so far, dichloro-diphenyl-trichloroethane (DDT), seems suitable for the disinsectization of aircraft. γ-Benzene hexachloride (Gammexane) is not to be recommended because of its disagreeable musty odour. β-Butoxy-β-thiocyano-diethyl ester (Lethane 384) is irritating to the skin integument and its odour is also disagreeable and enduring.

The effect produced by DDT is irreparable, although it is slower-acting than pyrethrin, and insects die only after a number of hours. For this reason a certain quantity of pyrethrin is often associated with it, its immediate paralytic effect preceding that of DDT.

Because of the low solubility of DDT in water, the most generally used preparation is a 5% DDT solution in kerosene, volatilized by means of a compressed-air sprayer which produces a cloud of fine particles. Garnham noted that 10 minutes' exposure to a dose of 30 ml. of this solution per 1,000 cubic feet killed all the test mosquitos in seaplanes treated by this method at Kisumu.

Solutions combining pyrethrin and DDT generally correspond to one of the following formulae:

0.05% pyrethrin with 0.3% DDT
or 0.03% pyrethrin with 0.5% DDT

diluted with kerosene, and if possible with the addition of 5% mineral oil.

Mineral oil is an effective activating agent and is preferable to sesame oil which was used formerly and whose affinity for DDT increased the toxicity of insecticidal solutions.
Moreover, DDT has considerable residual powers and its insecticidal effect is not, as is the case with pyrethrin, limited to the period of application. When it is placed on a wall, its toxicity for insects coming into contact with the wall lasts for several weeks.

It has been noted that, because of vibrations, insects in aircraft tend to stick on partitions as soon as the engines are started (Swain et al. 72). It was therefore considered advisable to make use of the residual toxic effect of DDT sprays in an attempt to obtain lasting protection of aircraft against mosquitos and other insects which might be lodged in them.

However, this surface disinsectization, which will be discussed later in connexion with methods of dispersing insecticides, can affect only insects coming into contact with it. Mosquitos resting on baggage, freight or the clothes of passengers are not affected. This type of disinsectization cannot therefore be used alone and does not dispense with mosquito-eradication by knock-down action, which is obtained by insecticidal sprays in cloud or aerosol form. Nevertheless, it is a complementary operation whose usefulness is all the greater as it is effective for species of insects other than mosquitos.

Toxicity of DDT to man. In France, dichloro-diphenyl-trichlorethane is placed in the category of poisonous substances, in table C. In the USA, the War Food Administration had, in 1944, admitted its toxicity and recommended that personnel in charge of spraying should wear masks and protective clothing in order to avoid absorbing it through the skin, or in breathing. As a matter of fact, accidents which have been noted generally seem to be attributable to the use of DDT solutions in mineral oil—oils increase the toxicity of DDT—or to the ingestion of food which has been contaminated by this product.

DDT-resistant insects. The existence of DDT-resistant Musca domestica has been observed in Sweden and Italy, as well as the appearance of resistant strains of this species after repeated exposure to DDT in laboratories. Further research should be carried out with regard to mosquitos, although so far no species of Anopheles has been found to be resistant to DDT.

It is therefore possible to state that pyrethrin and DDT used either separately or, preferably, together, are at the present time the most suitable insecticides for the eradication of mosquitos from aircraft.

Pyrethrins when used alone produce a complete lethal effect with a minimum dose of 0.1 g. per 1,000 cubic feet of enclosed space requiring treatment, and offer the advantage of bringing about the immediate paralysis of insects.

DDT used alone has a delayed but irreparable action. Its association with pyrethrin produces a more rapid toxic effect and makes it possible to reduce the quantity of pyrethrin—the costly part of the insecticide—without reducing its efficacy.
A study of the pyrethrin-rotenone combination, which is innocuous to man, should be made, as it produces an effect on a larger number of insect species and may be effective against agricultural pests.

3. METHODS OF APPLICATION OF INSECTICIDES

In order to be effective, mosquito-eradication operations should aim at dispersing the insecticidal solution in the form of a stable cloud of fine particles, which will diffuse rapidly to all protected or hidden parts of the cabin, of the control room, and of freight compartments; the spray should be sufficiently powerful to reach certain recesses which are particularly high above the ground, such as are found in the undercarriage well, and should not be wetting, so as to avoid soiling upholstery, papers and clothing.

Such insecticidal clouds can be produced either by automatic sprayers operating under adequate pressure or by the complete diffusion of the insecticidal liquid in aerosol form.

3.1 Automatic Spraying

Small hand-sprayers, such as "Flit guns", have been rapidly abandoned because of their inadequacy. Symes reports that, out of 23 aircraft, which on inspection on landing at Kisumu in 1934 revealed the presence of live mosquitos (Anopheles funestus, Anopheles gambiae, Culex, etc.), 15 had been disinsectized by means of a pyrethrum solution sprayed with Flit guns.

At the present time compressed-air sprayers are used, which operate under a pressure of at least 3 kg. per square centimetre (42.6 pounds per square inch). This pressure is obtained by means of a hand compressor, an electric compressor or, more simply, with a bottle of compressed air, provided with a pressure-reducer, which can be found in any normally-equipped aerodrome.

The sprayer should have a reservoir of sufficient capacity and preferably of graduated glass, so that the amount of sprayed insecticide can be readily computed.

At the present time there is no commercial difficulty in obtaining satisfactory sprayers, but, in their absence, a compressed-air spray-gun for cellulose painting may be used for this type of operation.
3.2 Insecticidal Aerosols

Aerosols are formed by the dispersal in the atmosphere of very fine spherical liquid particles (diameter less than 25 microns) which diffuse rapidly in the surrounding gaseous atmosphere where they remain suspended, their very small size and powerful surface-tension resulting, to a great extent, in their not being influenced by gravity. The mist formed by these particles spreads rapidly, being carried along by currents created by differences of temperature between the different layers of air. It penetrates in smoke-like fashion into interstices, takes several hours to settle when there is no ventilation, and does not wet surfaces with which it comes into contact.

Insecticidal mists composed of large liquid particles vaporized by automatic sprayers act on insects by contact. Their efficacy thus depends on the concentration of the insecticide in the air, and on its diffusion into all parts of the area to be disinsectized. When these two conditions are not fulfilled, especially in places which are not easily accessible, certain insects may escape the effect of the insecticide or may be only temporarily stunned.

An insecticidal aerosol, on the other hand, spreads rapidly in the air through convection currents and reaches insects wherever they may be. As these particles lack wetting properties, it appears that their toxic effect is produced differently. Instead of coming into contact with the insect’s waxy epicuticle, the effect is probably produced, through the respiratory system, on the tracheal tubes. Moreover, winged insects are more sensitive to aerosols than Aptera.

For the destruction of mosquitos in aircraft, insecticidal aerosols present numerous advantages. Foremost among these are: total absence of fire risk—when an inflammable product is completely diffused in aerosol form it loses its inflammability—and economy in insecticide. The complete diffusion in aerosol form of 1 ml. of liquid, in particles with a diameter of 5 microns produces 15,000,000 particles covering a surface of 120 square metres. According to Lock,36 the complete diffusion of 1 pint (0.568 l.) of insecticide (pyrethrin, rotenone, DDT) suffices for the destruction of insects flying in an enclosed space of 20,000 to 30,000 cubic feet (560 to 850 cubic metres). The required concentration is from 1/500,000 to 1/1,000,000 ; i.e., one-tenth or one-twentieth of the concentration needed, making allowance for temperature, atmospheric pressure and relative humidity, to produce a deposit or an adequate condensation of insecticide by saturation of the surrounding atmosphere.

According to Lock,36 the most rapid toxic effect would seem to be obtained with particles of 12 to 15 microns in diameter. The effect is not instantaneous and remains dependent on :

(a) the time required for insects to absorb the lethal dose of the toxic substance used,
(b) the kind of insecticide,
(c) the species of insect.

The most suitable base for an insecticidal aerosol seems to be deodorized kerosene. It has the advantage of having a low specific gravity, which increases the speed of dispersal, and slight surface-tension, which favours its absorption through the breathing system of insects. A visible mist, non-toxic to man, is obtained, which makes possible the supervision of the operation.¹

It will thus be readily understood why health experts have paid particular attention to the possibility of using insecticidal aerosols for the disinsectization of aircraft. As far as we know, the first experiments were made in 1938, under the direction of Mackie & Crabtree,¹² in Imperial Airways clipper flying-boats. An aerosol was produced by means of a portable apparatus (Phantomyst) and the liquid diffused was an aqueous solution of a concentrated pyrethrum extract. Results were most satisfactory.

3.2.1 Aerosol bombs

According to McFarland,¹⁷ Sullivan in 1942 used the same technique and simplified the aerosol-producing apparatus by using as a propellant the pressure produced inside a closed cylinder by dichloro-difluoro-methane (Freon 12), a gas which readily liquifies on compression and which vaporizes at a low temperature.

The original formula, studied by Goodhue & Sullivan at the US Bureau of Entomology and Plant Quarantine, and especially prepared for mosquito destruction in aircraft, was composed of:

- Pyrethrin . . . . . . . . . 4%
- Sesame oil . . . . . . . . 8%
- Freon 12 . . . . . . . . 88%

The mixture was contained in a sealed container, capable of bearing a pressure of approximately 6 kg. per square centimetre, with a valve shutting off a spraying orifice. On opening the valve for 4 seconds, a sufficient quantity of insecticide was volatilized for the eradication of mosquitoes in an enclosed space of 1,000 cubic feet within a few minutes.²

This formula was found to be very effective against mosquitoes, but much less so against flies when using the usual dosages. Further study revealed

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¹ Aqueous solutions of pyrethrum extract, or aqueous emulsions of 1% DDT, produce an odourless and invisible aerosol, which, although pleasanter for the passengers, does not give the operator complete confidence in its effectiveness.

² In reality, the droplets of Freon 12 expelled while the valve is open are of varying dimensions, but the rapid evaporation reduces the mass of the larger ones and, in practice, most insecticidal substances finally evolve into aerosol form.
that the addition of DDT increased the effectiveness of the aerosol and made it possible to reduce the quantity of pyrethrum. The formula was modified as follows:

Formula G-179: 

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrethrin</td>
<td>0.4%</td>
</tr>
<tr>
<td>DDT</td>
<td>3%</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>5%</td>
</tr>
<tr>
<td>Mineral oil</td>
<td>2%</td>
</tr>
<tr>
<td>Freon 12</td>
<td>84%</td>
</tr>
</tbody>
</table>

A formula comprising a larger quantity of pyrethrin was subsequently perfected:

Formula G-382: 

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrethrin</td>
<td>1%</td>
</tr>
<tr>
<td>DDT</td>
<td>3%</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>5%</td>
</tr>
<tr>
<td>Mineral oil</td>
<td>2%</td>
</tr>
<tr>
<td>Freon 12</td>
<td>85%</td>
</tr>
</tbody>
</table>

Under normal conditions, a dose of 4 to 5 g. (or approximately 0.05 g. pyrethrin), dispersed in an enclosed space of 1,000 cubic feet, results in a 100% kill of flies and mosquitoes. In spite of the DDT content, no residual activity is to be expected.

Because of the limited space which it occupies, its very small weight (600 to 700 g.), the ease with which it can be manipulated, and its effectiveness, the Freon insecticidal bomb constitutes a practical and inexpensive means of carrying out mosquito destruction in aircraft by means of aerosols. Formula G-382 has been retained by the US Public Health Service, which has recommended its use for aircraft in place of earlier formulae.

However, certain criticisms can be made regarding its present commercial forms:

1. Air navigation companies and certain health services still use Freon bombs whose pyrethrin content is only 0.2% to 0.4%.

2. The amount of insecticide dispersed by the bomb is empirically calculated by the time during which the valve or tap remains open (4 to

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k Cyclohexanone is an auxiliary DDT solvent. The presence of DDT renders the aerosol toxic to flies. It was necessary to retain a sufficient amount of pyrethrin, whose immediate stunning effect on insects reinforces the toxic effect of DDT, which, though slower, is irreparable. Freon 12 is used both as a solvent and propellant, and vaporizes instantly at ordinary temperatures. Aerosol droplets leave no residue on partitions or furniture, providing the bomb is held at least two feet (about 60 cm.) away during spraying operations.

l The cost of an aerosol insecticidal bomb with a capacity of about 16 ounces (450 g.) is at present approximately 2 dollars.
5 seconds for an enclosed space of 1,000 cubic feet). Results therefore lack uniformity, as:

(a) the flow varies proportionately with the temperature of the insecticidal solution;

(b) although the capillary tube in standard Westinghouse valves has an interior diameter of 0.017 inches (0.425 mm.), there are considerable variations in the flow from aerosol bombs of the same or of different manufacture.

It would appear that a proportion of the failures observed after operations carried out according to such a rule-of-thumb requirement as the computation of an amount of insecticide by the duration of the gaseous outflow of a Freon bomb, can be attributed to these factors. While carrying out investigations in 1946 in seaplanes, at a temperature of 24° to 26° C. and a relative humidity of 50%, Garnham noted that, with a spraying-time of 4 seconds per 1,000 cubic feet and an exposure to the action of the aerosol of 10 minutes, 4 out of 72 test mosquitos (3 Aedes taeniorhynchus and 1 Aedes aegypti) were still alive after 12 hours. On the other hand, longer exposure and higher concentrations produced a 100% kill. He concluded that Freon insecticidal bombs are satisfactory when the doses used are greater than those usually prescribed.

To conclude, if formula G-382, which is particularly useful in view of its high pyrethrin content, must be recommended for insecticidal aerosols, it would be advisable that manufacturers should guarantee a relatively constant outflow, obtained by means of a suitable valve, of not less than 60 g. of insecticidal solution per minute at a temperature of 20° to 25° C.

Toxicity of DDT aerosols. It appears, from investigations carried out by the Division of Industrial Hygiene of the US National Institutes of Health, that the inherent toxicity of DDT, when used in solution at 1% to 5%, with 10% cyclohexanone and 85% to 89% Freon, and dispersed in aerosol form, is not dangerous when employed under the conditions required for its use as an insecticide. Neal et al. state that DDT solutions in oils increase in toxicity and that the results obtained with a DDT solution in cyclohexanone are not necessarily comparable with the effects produced by an oily solution.

3.3 Equipment for Automatic Disinsectization of Aircraft

The automatic destruction of mosquitos in aircraft by means of a system of insecticide distribution controlled from the cockpit, with connexions in each compartment of the aeroplane that might be harbouring insects,

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*m On weighing successively the outflow of two new aerosol bombs of the same make at 18° C., it was found that the average outflow was 26.5 g. per minute for one, and 18 g. per minute for the other. A low-pressure Flit aerosol bomb discharged 44.5 g. of insecticide per minute at the same temperature.
is not a new problem. A study of the question was begun in 1937 by Imperial Airways medical services with regard to clippers, and was pursued by the Pan American Sanitary Bureau and the US National Institutes of Health.

The advantages which are to be derived from a permanent installation are, in fact, considerable:

(a) operations can be conducted from the cockpit, under the direct supervision of the captain, and are no longer left to the responsibility of stewards;

(b) operations can be carried out during flight, thus reducing the loss of time incurred as a result of disinsectization operations before taking-off or after landing;

(c) the insecticide can be more evenly dispersed;

(d) supervision by health authorities is simplified and may entail only the checking of the amounts of insecticide which have actually been sprayed.

Such equipment should be sturdy, light in weight, inexpensive and easily maintained in order.

The first attempt to solve the problem consisted of a distribution system comprising a single reservoir of insecticide connected to various parts of the aircraft by a series of tubes. This did not prove to be entirely satisfactory, and Snow therefore recommends the use of numerous low-capacity reservoirs filled with insecticidal aerosol (5 ounces or 142 g.) and fitted in various parts of the aircraft. Outflow valves are operated by a solenoid valve controlled electrically from the instrument panel, thus avoiding the necessity of laying, checking and maintenance of pipes. In the cockpit are two automatic counters which record respectively the length of time taken by the electric current to pass through the solenoid valves during each disinsectization operation, and the order of operations carried out. The total weight of such equipment would be about 13 pounds (6 kg.), 3 pounds (1.4 kg.) of which would be insecticide, comprising 10 spraying units suitable for DC-3 or C-47 aircraft. The amount of insecticide allowed should suffice for carrying out 20 to 30 successive spraying operations.

The apparatus suggested by Snow is worthy of note and should be taken into consideration when equipping aircraft which do not have pressurized cabins. Objections have been put forward, such as the weight of the distribution system, and the need for frequent refilling of reservoirs because of their limited capacity, but such objections do not seem to outweigh the advantages of the system. A study of low-pressure liquid propellents (similar to the mixture of Freon 11 and 12 used in Flit bombs), which are free from any danger of exploding upon the abnormal heating

\[n\] A pressurized cabin is an air-tight cabin kept under constant pressure.
of the liquefied gas contained in the reservoirs, is, however, to be recommended, so as to increase the safety of the apparatus.

Automatic disinsectization of this type is not applicable to long-range aircraft with pressurized cabins, at least during flight. Because of the special ventilation and air-conditioning system with which such aircraft are equipped, it is not technically feasible to interrupt the functioning of cabin compressors and ventilators during flight. As these cause a constant movement of air, the density of a sprayed insecticidal aerosol would not be uniform and its efficacy would thus be reduced.

For such aircraft, it would be advisable to study the possibility of connecting the main air-conditioning pipes with a mixer which would make it possible to disperse, in the moving air, a quantity of insecticidal aerosol calculated on the basis of the outflow of the pressurization and ventilation system. The problem is not easy to solve, as the outflow varies according to the type of aircraft, and it is possible that the mixing of moving air would modify the stability of the aerosol.

As, at the present time, there is no simple automatic apparatus which can be fitted in long-range aircraft with pressurized cabins, it is still necessary to use classical disinsectization methods, and, as will be seen later, such methods would appear to be applicable only to parked aircraft.

### 3.4 Disinsectization through Residual Toxicity

Laboratory and other experiments indicate that the efficacy and duration of the residual insecticidal effect of a surface sprayed with DDT solution are related to the quantity of active substance deposited per unit surface.

According to Hocking, an application of 200 mg. DDT per square foot (2.15 g. per square metre) produces an almost 100% kill of *Anopheles gambiae* and *Anopheles funestus*, the toxic effect lasting for four to six months. According to Fay, Simmons & Clapp, deposits of 300 to 400 mg. per square foot (3.2 to 4.3 g. per square metre) do not give such superior results, compared with deposits of 200 mg., that the added expense can be justified.

The application of DDT to plain wood, cloth, dry paint and French polish is effective and lasting. On bare metal surfaces, the duration of residual toxic action would be less—from two to three months—because of the more rapid mechanical wearing-away of the toxic film.

However, it would seem that agreement has not yet been reached on the actual duration of the residual insecticidal effect of DDT sprayings in aircraft. Using the fly as a test insect, Pratt obtained only a 42% kill three weeks after the application of DDT to upholstered aeroplane partitions, and no lethal effect whatever on bare metal partitions after
two weeks. However, according to this author, surfaces upholstered with woollen materials retain considerable residual toxicity 90 days after being treated with DDT sprays.

In 1946, the Task Committee on the Disinsectization of Airplanes argued on the advisability of repeating every 30 days the disinsectization by residual toxicity of military transport aircraft, in order to maintain an effective toxic density on as wide a surface as possible. According to Pratt, commercial aircraft should be disinsectized more frequently.

These differences of opinion may be explained partly by the amount of insecticide sprayed per unit surface and partly by the standard of spraying operations. Boyer, the chief medical officer of the airports of Orly and Le Bourget, expressed the opinion during the course of a discussion at the Congrès français d'Hygiène in 1947 that the spray should not produce too fine a mist, as in such a case solutions tend to pass through material without adhering to the surface. Account must also be taken of the wearing-away, to a greater or less extent, of the film of toxic substance, as the result of rubbing due to contact with passengers, to the handling of baggage and to cleaning operations in cabins, which are generally carried out by means of vacuum cleaners.

To conclude, it is permissible to assume that the surface application of DDT sprayed on the interior partitions and furnishings of aircraft so as to produce a concentration of at least 200 mg. per square foot (2.15 g. per square metre) constitutes, by its residual toxic effect, an efficient protective measure for aircraft against accidental or permanent infestation by insects. The duration of such residual toxic effect can be estimated at approximately one month for aircraft carrying out normal commercial operations. It is, however, difficult to obtain a definite opinion and further research would appear necessary.

4. DISINSECTIZATION OF AIRCRAFT

As the result of an inquiry, undertaken in December 1947 by the Interim Commission of the World Health Organization, to which replies have been received from 42 States, 2 international aviation organizations, and the Pan American Sanitary Bureau, it would appear that:

15 States have, at the present time, no clearly defined methods for the disinsectization of aircraft, either because their climatic and geographical conditions are unfavourable to the introduction of exotic insects, or because

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6 We were unable to find any indication of the density of insecticide per unit surface which Pratt obtained during his experiments.
international air travel through their territory is so limited that such prophylactic measures are not yet necessary;

8 States prescribe the use of the Freon insecticidal aerosol bomb;

8 States require the use of either the aerosol bomb or insecticidal sprays containing pyrethrin with or without addition of DDT;

3 States rely entirely on spraying insecticidal solutions containing pyrethrin and DDT;

8 States recommend DDT alone, dispersed in various forms.

In addition, 6 States recommend, though they do not enforce, the complete periodical disinsectization of aircraft, by utilizing the residual properties of DDT solutions.

The pyrethrin content of liquid insecticides, the quantity of insecticide to be dispersed in a given enclosed space, the duration of exposure to the insecticide, and the time when disinsectization operations should be carried out, all vary similarly from State to State.

Questioning of aircraft crews has shown that at times they interpret instructions regarding such operations in very different ways, either because they are not aware of the importance of such instructions, or because variations in sanitary regulations create, understandably, a certain amount of confusion.

Finally, when the sanitary regulations of various countries with regard to aerial navigation are analysed, it is noteworthy that the measures laid down concern aircraft arriving in their territory, while mention is rarely made of measures to be imposed on departure from that territory.

This negative attitude, in which each country concentrates on protecting itself from outside infection rather than on paying attention to the source of danger it may be to other countries, is not in line with the general rules of effective prophylaxis. It is more important to prevent the departure of possible vectors of disease than to attempt to prevent their spread later, when they have made their appearance in non-infected areas.

It will thus be seen that there is a practical need for the international standardization, not only of the technique of disinsectization of aircraft, but also of the general rules to be followed for the application of this prophylactic measure.

For this purpose, the following should be defined:

1. aircraft requiring disinsectization;
2. suitable insecticides;
3. time when disinsectization operations should be carried out;
4. method of conducting such operations;
5. authority responsible for their implementation.
4.1 Definition of Aircraft suspected of being Infested

The disinsectization of aircraft on airfields situated in an endemic yellow-fever area, and particularly on departure from the last airfield situated in such an area, is laid down in Article 38 of the International Sanitary Convention for Aerial Navigation of 1933/1944. A further disinsectization is to be carried out on the arrival of such aircraft on the first airfield situated in a region free from yellow fever, but where conditions might permit its development (Article 47), and, possibly, on landing in areas where conditions are not favourable to the spread of yellow fever (Article 51). The same provisions apply to aircraft leaving an area infected with malaria or other diseases which are spread by insects (Article 54).

The provisions of Articles 38, 47, 51 and 54 of the Convention do not seem to cover all contingencies. *Aedes aegypti* is a mosquito which propagates in many regions outside recognized endemic yellow-fever areas. Consequently, an aeroplane which, without having at any time landed in a yellow-fever area, happens to be transporting a person suffering from yellow fever in an apparent or latent form, may also be harbouring a number of *Aedes aegypti*, and may therefore be a possible source of infection, should these mosquitos become infected through contact with vectors of the yellow-fever virus.

This possibility, however unlikely it might appear in view of the number of circumstances required for its realization, has not escaped the notice of health authorities in certain areas, who believe themselves, because of their geographical position, to be particularly threatened. Such a possibility should be included in the definition of aircraft requiring disinsectization, and may be briefly stated as follows:

"The following may be suspected of transporting insect vectors of malaria, yellow fever or other diseases, and must, on this account, be disinsected before departure:

1. any aircraft taking off from an airport situated:
   (a) in one of the endemic yellow-fever areas delineated by the World Health Organization;
   (b) in a recognized endemic malaria area;
   (c) in an area where, in the opinion of the World Health Organization, a contagious disease, transmissible by insects and liable to constitute a danger for other countries, is raging.

2. any aircraft which, without having landed in, or taken off from, an endemic yellow-fever area in the course of its flight:
   (a) is transporting one or more passengers suffering from yellow fever;
   (b) is transporting one or more passengers having arrived from an endemic yellow-fever area within less than 9 days and not in possession of a valid certificate of inoculation or of immunity against yellow fever."
“Moreover, a supplementary disinsectization can be required by health authorities of all aircraft mentioned in paragraphs 1 and 2 above before arriving or immediately after landing on an aerodrome situated in a territory or region in which yellow fever or malaria do not exist, but where conditions might permit their development.”

4.2 Type and Quantities of Insecticides

Experience has shown that insecticidal diffusion in aerosol form is the least obnoxious for the occupants of an aeroplane; aerosols have the added advantage of being non-inflammable and can thus be used during flight. However, for exterior parts of aircraft (undercarriage, split-wells, etc.), it would seem preferable to use insecticidal solutions sprayed by compressed-air sprayers, as these are easier to direct effectively into those recesses which, because of their awkward position, are generally out of reach of the vertical spray from aerosol bombs.

It appears possible to define the type of insecticides and their quantities to be recommended as follows:

“1. The disinsectization of all interior parts of aircraft is to be carried out with one of the three following preparations:

(a) a pyrethrum and DDT aerosol, containing at least 1% by weight of pyrethrins I and II and 3% by weight of DDT, dispersed by means of an aerosol sprayer at the rate of 50 mg. pyrethrin per 1,000 cubic feet (1.75 mg. per cubic metre) of enclosed space requiring treatment;\(^p\)

(b) a standard solution of pyrethrum extract, used either as a freshly prepared aqueous emulsion or in solution in completely volatile kerosene, which does not soil and whose ignition point is not less than 49°C (120°F). The quantity of emulsion or of solution sprayed should correspond to at least 100 mg. pyrethrin per 1,000 cubic feet (3.5 mg. per cubic metre) of enclosed space requiring treatment;\(^q\)

(c) a pyrethrin and DDT solution, containing at least 0.1% by weight of pyrethrins I and II and 0.3% by weight of DDT, in completely volatile kerosene, which does not soil and whose ignition point is not less than 49°C (120°F). The quantity of solution sprayed should correspond to at least 50 mg. pyrethrin per 1,000 cubic feet (1.75 mg. per cubic metre) of enclosed space requiring treatment.

The spraying of insecticidal emulsions and solutions (b) and (c) will be carried out by means of an automatic sprayer functioning under a pressure of not less than 3 kg. per square centimetre (42.6 pounds per

\(^p\) This corresponds to a spraying for 5 seconds with an aerosol bomb with an outflow of 60 g. of G-382 insecticidal mixture per minute.

\(^q\) This corresponds to the use of approximately 6 ml. of standard 2% pyrethrum extract per 1,000 cubic feet, or 30 ml. of one-fifth emulsion in water, or of one-fifth solution in kerosene respectively.
square inch) and dispersing a fine, stable mist. Because of the inflammable nature of kerosene vapours, such insecticidal solutions will be used only when the motors of the aircraft are stopped. When electric or petrol motor compressors are used to produce compressed air, they will be kept at a safe distance.

“Cabin ventilators will be closed, and doors, portholes, wind-shields and other apertures in the aircraft will be kept tightly closed during the spraying of the insecticide, and for a period of not less than 5 minutes following the operation.

“Any food which may be in the aircraft will be protected from all contact with insecticide sprays containing DDT.

“2. The disinsectization of exterior parts of the aircraft which might form resting places for insects, or of parts of the aircraft which are accessible only from the outside (undercarriage or split-wells, freight or bomb compartments), is to be carried out with the insecticidal solution mentioned in paragraph 1 (c). The operation should be carried out 5 minutes before starting the motors, or, on landing, for parts of the aircraft near the motors, as soon as the latter have cooled sufficiently to avoid any fire risk.

“The quantity of insecticide to be sprayed in any aperture which cannot be closed will be equal to at least twice the amount prescribed for an enclosed space of corresponding size.”

4.3 Appropriate Time for carrying out Disinsectization

A wide range of opinions is encountered on the question of the appropriate time for carrying out disinsectization operations in aircraft. Certain States recommend or stipulate that they should be performed:

- immediately before or after taking-off (Chile);
- one hour after taking-off from the last stop, and one hour before landing (Philippines);
- 30 minutes before landing (United States, ICAO);
- immediately after landing (Australia, Brazil, Egypt, Union of South Africa).

From an epidemiological point of view, it appears preferable to eradicate insect vectors of diseases from aircraft suspected of harbouring them immediately before leaving an infected area, or one suspected of being so. This offers a safeguard to health for the crew and passengers (especially in the case of malaria) as regards the interior of the aeroplane, and at the same time is a useful protective measure, for the territory in which the next port of call is situated, against possible shelters for insects on the exterior parts of the aircraft, which are inaccessible during flight.

Moreover, disinsectizations carried out during flight cannot, at least
in their present form, offer a sufficient safeguard to health in certain types of aircraft such as:

(a) long-range aircraft with pressurized cabins, in which it is not possible to stop air circulation during flight, the "dumping" of superchargers creating a sudden restoration of pressure to that of the actual altitude of the aircraft (15,000 to 18,000 feet, or 4,500 to 5,500 m.);

(b) large military aircraft, because of the number of apertures (turrets, gun-openings) which favour the escape of the insecticide.

An inquiry carried out in 1943 by Oswaldo Aranha on aircraft of the South Atlantic Air Transport Command had drawn attention to this fact. Swain et al.\(^7\) have pointed out the inefficacy during flight of the usual aerosol bomb for this type of aircraft, and, according to Klots,\(^8\) when using doses which are prescribed for mosquitos, it is effective on the ground only after the motors have been stopped.

These technical considerations show the impossibility of defining a uniform method applicable to all types of aircraft, and necessitate the following differences when carrying out disinsectization operations:

4.3.1 *Disinsectization on departure*

1. For all aircraft:

(a) baggage and freight compartments are to be disinsectized after loading and immediately before being finally closed;

(b) the undercarriage and all other parts of the aircraft accessible only from the outside and capable of harbouring insects are to be disinsectized 5 minutes before the motors start running.

2. (a) For long-range aircraft with pressurized cabins, in addition to the measures prescribed in paragraph 1, the disinsectization of cabins and annexes, as well as cockpits and annexes, is to be carried out after the closing of the doors and windscreen, during the time between the departure from the parking area and the end of the warming-up of the engines. The superchargers will not be connected with the cabin, and auxiliary ventilators will not be put into operation, until 5 minutes after the spraying of insecticide has been completed.

(b) For aircraft with non-pressurized cabins, in addition to the measures prescribed in paragraph 1, the disinsectization of cabins and annexes, as well as cockpits and annexes, is to be carried out 10 minutes after taking-off, after the portholes and windscreen have been closed and the cabin ventilators stopped. The ventilators will not be started again until 5 minutes after the spraying of insecticide has been completed.

(c) For military aircraft other than transport aircraft, in addition to the measures prescribed in paragraph 1, the disinsectization of cabins and annexes, as well as cockpits and annexes, is to be carried out with all apertures closed, 5 minutes before starting up the motors.
4.3.2 Disinsectization on arrival

1. For all aircraft:
   Baggage and freight compartments, the undercarriage and all other parts of the aircraft accessible only from the outside and suspected of harbouring insects are to be disinsectized on landing, as soon as the motors have cooled sufficiently to avoid any fire risk.

2. (a) For long-range aircraft with pressurized cabins and military aircraft other than transport aircraft, cabins and annexes, as well as cockpits and annexes, are to be disinsectized on landing, immediately after the motors have been stopped.
   (b) For aircraft with non-pressurized cabins, cabins and annexes, as well as cockpits and annexes, are to be disinsectized:
       either at least 10 minutes before landing;
       or, on landing, immediately after the motors have been stopped.

4.4 General Procedure for Operations

No very detailed study has been made on the places of refuge which the various types of aircraft at present in use can afford for insects. In practice, captured insects have generally been discovered in the cockpit, in the passengers' compartment, under seats and in very dark corners of the cabin.

In summarizing reports by civil and military health authorities in the USA, White 81 indicates that the places which would seem more likely than others to harbour live insects of various species are:
   navigator's and radiotelegraphist's cockpits;
   the main passenger cabin;
   lavatories;
   baggage compartments;
   spaces beneath the cabin floor.
   For military aircraft, automatic gun-turrets should be added.
   The interior of the wings of certain types of aircraft, wheel wells in the undercarriage, split wells in the wings (Fowler flaps), the tail of the fuselage—all these can also constitute resting places for insects.

On the other hand, the frames of air-cooled engines and engine nacelles placed in front of fire walls, seem unlikely to harbour live insects because of high temperatures and powerful wind-currents. Ventilation pipes opening out on the leading edge of the wings, air-tight ailerons, rudders and metallic stabilizers, and most likely the space between the upholstered interior of the cabin and the exterior wall of the fuselage can likewise be dismissed.

Moreover, the better aerodynamic shape of modern transport aircraft has resulted in the progressive disappearance of the numerous recesses
and outside depressions which Cumming\textsuperscript{11} mentioned in 1938 as being able to harbour mosquitoes. Nowadays, metallic wings have relatively air-tight inspection flaps, and the canvas-covered ailerons alone, which have a series of apertures 7 to 10 mm. in diameter, provide access to the hollow wing. These might allow some insects to enter, which would find a safe resting place inside the wing. As some of these ailerons are inaccessible from the ground, it would be useful to cover their openings by a grill.

### 4.4.1 Disinsectization of the interior of the fuselage

When disinsectization takes place before departure, it should be carried out after the aircraft has been completely loaded, when passengers and crew have taken their seats in the cabin and cockpit, and after the closing of doors, portholes, hatches and all other outer openings which will be kept closed until after taking-off.

In order to make sure that the insecticide is properly distributed, the operator should move about in the interior of the aircraft and spray the cloud into all accessible parts. When an aerosol bomb is used, it should be held vertically, in order to obtain an aerosol dispersion and not a spray of large drops of liquid.

Special care should be taken in spraying cupboards, chests, life-saving equipment, as well as cabin cloakrooms where passengers and crew hang their clothes and which may possibly constitute resting places. Garnham\textsuperscript{19} has been able to prove that clothing, blankets and the upholstered interior of aircraft can become shelters for mosquitoes because of the fact that they protect insects against the action of insecticides. The effectiveness of an insecticidal aerosol on a cage of mosquitoes covered with a cloth is practically nil, even for high concentrations of insecticide, as, on contact with the cloth, aerosol particles rebound without penetrating. In experiments under such conditions with a Freon bomb, Garnham noted that:

- for a spraying of 1,000 cubic feet for 10 seconds, of 18 mosquitoes, none was killed:
- for a spraying for 68 seconds, 2 of 6 mosquitoes were killed.

The amount of insecticide dispersed should be proportional to the size of the enclosed space to be disinsectized. The US Public Health Service (Circular No. 77) has suggested the following formula for making an approximate calculation of an aircraft’s capacity:

\[ \text{maximum length} \times \text{maximum height} \times \text{maximum width}^r \times 0.8. \]

It would be preferable to insist that the builders or owners should put up a notice inside the aircraft giving the exact volume of each part of the fuselage, so as to avoid the use of undue amounts of insecticide, which are both irritating to the occupants and expensive for companies.

\textit{r} Measured in the centre of the fuselage
The length of exposure to the insecticide should not be less than 5 minutes, calculated from the completion of the spraying. If the aircraft is still on the ground at the end of this period, cabin ventilators can be opened, but the doors, portholes and windscreen will be kept fastened until after taking-off, in order to prevent the introduction of further insects.

When disinsectization is carried out on arrival, all exterior apertures of the aircraft must be closed before landing to prevent the escape of live insects. Cabin ventilators will be closed during spraying and for 5 minutes afterwards. The doors will only be opened 5 minutes after the spraying of insecticide has been completed.

It should be emphasized that insecticidal aerosols are generally less disagreeable for passengers than the automatic spraying of mists, and that, from a psychological point of view, disinsectization carried out on departure, or at the beginning of the flight, arouses less opposition than when carried out on arrival, as passengers, who are already fatigued through a long period of sitting and who are anxious to land, wish to disembark immediately.

4.4.2 Disinsectization of exterior parts of the aircraft

At present, attention is not very often paid to the exterior parts of aircraft. This is a regrettable omission.

Baggage and freight compartments opening on the outside should be disinsected after loading and immediately before being finally closed.

It is also essential to spray the recesses opening under the wings: under-carriage, wing hatches and flap housings. These deep and inaccessible hollows afford excellent shelter for winged insects which, during the flight, will find refuge there against air currents. The disinsectization of these parts of the aircraft on departure is therefore useful in order to prevent the escape of live insects on landing. The use of aerosols does not seem of value because of the impossibility of closing such spaces when the aircraft is grounded. It is preferable to use sprays of pyrethrin and DDT producing a damp mist. The insecticide is deposited on the interior surfaces of the hollows and produces an immediate toxic effect, due to pyrethrin, and a residual toxic effect, due to DDT. When correctly carried out 5 minutes before starting the motors, this operation should be sufficiently effective not to require repetition after landing.

4.4.3 Surface disinsectization with residual effect

This operation is a useful addition to disinsectization by knock-down action but can never offer sufficient health protection when used alone.

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5 The violence of the air current in ventilators is sufficient to prevent insects which are still alive from entering the cabin.

6 Birds and even human beings have been carried in perfect safety in the undercarriage of certain types of aircraft.
It can be used with advantage as a routine measure during periodical inspections of aircraft.

The spraying of aqueous suspensions of DDT offers complete safety against fire risk, but has the disadvantage of occasionally leaving visible marks on material and upholstery. After drying and wiping, the DDT film will still have a satisfactory though, according to Klots, incomplete toxic effect.

5% DDT solutions in kerosene are more generally used. The spray should produce droplets which, to avoid soiling, should not be too heavy, nor, as micro-atomization makes the dispersed mist very slow in settling, too fine. After the kerosene has evaporated, a fine layer of DDT crystals, unaffected by vibrations during flight, remains on treated surfaces.

It is recommended that the quantity of insecticide deposited should be 200 mg. per square foot (2.15 g. per square metre). The average duration of the effect of the toxic film is as yet uncertain and would need to be determined by further research.

4.5 Authority Responsible for Operations

Sanitary regulations stipulating that the disinsectization of aircraft should be carried out during flight imply that the operation will be performed by one of the crew members, under the authority and responsibility of the captain of the aircraft (Australia, Chile, Philippines, Sweden, United States, Pan American Sanitary Bureau, ICAO). Conversely, States in which disinsectization is required immediately after landing delegate such work to the health authorities at the arrival airport (Brazil, Egypt, India, Pakistan, Union of South Africa). In actual fact, from the point of view of general prophylaxis, the most important disinsectization operations are those carried out on leaving an infected area. In view of the advisability of forbidding the subsequent opening of the cabin before taking-off, it seems best that these should become the responsibility of the captain of the aircraft, with the following provisos:

(a) disinsectization operations of external parts of the aircraft should be carried out either by means of equipment on board, or with the help of health authorities at the departure airport;

(b) disinsectization of the interior of the aircraft should be carried out by the crew with insecticidal apparatus which must be part of the normal equipment;

(c) records of disinsectization operations carried out on departure of the aircraft from an infected area must be kept and certified by the captain
of the aircraft on the General Declaration (Departure/Arrival) required by
the Convention on International Civil Aviation, and should state: "
the date and time of the operation,
the kind of insecticide used,
the parts of the aircraft treated.
As this measure is laid down in an international sanitary regulation,
and its importance is sometimes forgotten, it would perhaps be useful
to state precisely that:

(d) failure to carry out, on departure, the disinsectization of an aircraft
coming within the definition of an aircraft suspected of being infested
with insect vectors of disease constitutes an offence which can be reported
by the State on whose territory the fact was established to the State in
which the aircraft is registered.
Disinsectization carried out during flight must also be noted in the
General Declaration (Departure/Arrival).
Disinsectization to be carried out immediately on landing is the res-
ponsibility of the health authorities of the arrival airport, who alone are
in a position to judge its advisability or the parts of the aircraft requiring
treatment, taking into account the kind of disinsectization operations which
were carried out in the aircraft on its departure, as well as the method
of procedure followed and the apparent effectiveness of such operations.

4.6 Effectiveness of Disinsectization

Commenting on the problem, created by south transatlantic airlines,
of the possible reinfestation of Brazil by Anopheles gambiae, Farrell 7 suggests
that the disinsectization of aircraft is, by itself, a preventive measure
which is perhaps inadequate and should be supplemented by the dis-
infestation of departure airports in important endemic malarial areas.
Statistical studies by Miller, Burgess & Carpenter 48 seem to confirm
this point of view. From 1 July 1944 to 30 June 1945, 24,930 insects, includ-
ing 1,418 mosquitos, of which 158 were still alive despite disinsectization
measures, were collected in 12,367 aircraft arriving in USA territory.
These mosquitos included 1,339 culicines (of which 142 were living speci-
mens) and 79 anophelines belonging to 9 different species, 16 specimens
being still alive (see table II).
Anopheles pharoensis and an Indian culicine were the only two species
still unknown in USA territory. These authors also state that, during
the years 1943 to 1946, not a single exotic anopheline was captured alive
in aircraft in the USA, thanks to the effectiveness of measures undertaken.

* The present wording of this document mentions only one disinsectization operation. As, during a
single flight, an aircraft may make successive landings in infected areas, thereby falling each time into the
category of suspect aircraft, it would be advisable for a new edition of the document to provide space for
the entry of several disinsectization operations.
**Table II. Anophelines Found in 12,367 Aircraft Arriving in the USA, 1 July 1944 - 30 June 1945**

<table>
<thead>
<tr>
<th>Species</th>
<th>Dead</th>
<th>Alive</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. albimanus</td>
<td>24</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>A. crucians</td>
<td>19</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>A. grabhami</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>A. maculipennis aztecus (?)</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>A. neomaculipalpis</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>A. pharoensis</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>A. pseudopunctipennis</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>A. quadrimaculatus</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A. punctipennis</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Nyssorhynchus</td>
<td>8</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Unclassified</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>63</td>
<td>16</td>
<td>79</td>
</tr>
</tbody>
</table>

* On 5 airfields: Miami (Florida), Brownsville (Texas), Fort Worth (Texas), New Orleans (Louisiana), San Juan (Puerto Rico)

In spite of these favourable circumstances, and however slight may appear the risk of importing insect vectors of disease into non-infected territories when disinsectization is properly carried out, it is none the less important that control measures against mosquitoes in the vicinity of airports open to international traffic should be continued and developed.

**Conclusions**

As a result of this study, it seems possible to conclude that:

1. Because of the evident danger constituted by the possible air-transport of insect vectors of disease, it is advisable to obtain strict adherence to the stipulations of Article 54 of the International Sanitary Convention for Aerial Navigation of 1933/1944, which prescribes the disinsectization on departure of all aircraft leaving an infected area.

2. The disinsectization of aircraft, when carried out by the proper means, appears to constitute an effective prophylactic measure against such a danger. It cannot, however, by itself provide an absolute health safeguard.

3. It is therefore imperative, whenever environmental and climatic conditions are favourable, to maintain and develop control measures against mosquitoes in the vicinity of airports open to international air-traffic, in order to eradicate locally all agents which are vectors of malaria, yellow fever or other diseases spread by insects, or at least to limit the likelihood of mosquitoes penetrating into aircraft landing or parking on such airfields.

4. Moreover, in accordance with the recommendations of the Expert Committee on Malaria of the World Health Organization, and independently of disinsectization procedures for aircraft, it appears useful,
as a supplementary measure, to take steps towards permanent eradication of *Anopheles* from aerodromes and sea bases, in order that mosquitos which might possibly be introduced by aircraft into a territory, normally free, or which has been freed, from malaria, cannot find conditions favourable to their development.

5. Although technical means which are at present available for the disinsectization of aircraft offer appreciable health safeguards and can be carried out with reasonable ease, it would be useful if, with the object of improving the methods of dispersing insecticides and of rendering a larger number of insect species susceptible to their action, further research could be undertaken on the following lines:

(a) search for effective aerosols against the principal insect species usually encountered in aircraft, and especially against agricultural pests;

(b) determination of the duration of the residual insecticidal action of surface DDT applications in commercial aircraft in present use;

(c) study of automatic disinsectization procedures applicable to aircraft with pressurized cabins;

(d) drawing up of “standard instructions” for disinsectization, adapted to the different types of aircraft in use on international airlines, and suitable for posting in the interior of aircraft.

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