TESTS WITH AERIAL FOGS AND SPRAYS AGAINST ADULT MOSQUITOES

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Although insecticides dispersed at ground level can be very effective in killing adult mosquitoes, utilization of ground equipment is limited to those areas having access roads. The outbreak of mosquito-borne encephalitis that occurred in the Tampa Bay area of Florida in 1962 focused attention on the need for fast, effective vector control in large urban areas that are interspersed with inaccessible, undeveloped lands. Consequently, research with aerial applications against the proven vector, *Culex nigripalpus* Theobald (Chamberlain, 1963) was started in 1963 by the Control Research Section of the Entomological Research Center at Vero Beach. Owing to the interests of several mosquito control districts in aerial applications for control of salt-marsh mosquitoes, some tests with aerial fogs were conducted against *Aedes taeniorhynchus* in 1962 prior to the outbreak of encephalitis. The objective of the 1962 tests was to refine the aerial fogging operation described by Davis, *et al.*, (1960) as used for the control of adult salt-marsh mosquitoes.

Although *Aedes taeniorhynchus* were included in the 1963–64 tests, the principal objective of the research following the encephalitis epidemic was to develop an effective aerial operation for the control of *Culex nigripalpus*. Of special interest were the several types of habitats prevalent in the Tampa Bay area, especially swamps of red maple, *Acer rubrum* (L.), and hardwood forests, mostly *Quercus* sp., where large concentrations of *Culex nigripalpus* were known to occur. Brush plots of saw-palmetto, *Serenoa repens* (Bartr.), and gallberry, *Ilex glabra* (L.), also were used in the tests as well as open areas having only short grass similar to residential areas. This is a report of the results of this research from 1962 through 1964.

METHODS. In all tests, 2- to 8-day-old adult mosquitoes, reared in the laboratory from wild stock, were exposed in wire screen cages. Cages were of two types: the standard 3 x 6 inch wire screen cylinder (Rogers, *et al.*, 1957) and a flat, round cage 8 inches in diameter and 1 inch high having a solid metal side and screened on both sides. By means of a battery-powered aspirator, mosquitoes were placed in the flat cages through a one-half inch hole in the metal side, which was plugged with a rubber stopper. All tests with aerial sprays were conducted with this type of cage placed on 6 x 6 inch aluminum plates having the corners bent 90° to make four triangular prongs ⅜-inch high. The plates were placed on the ground with the cages resting on the upturned corners. The prongs were smeared with petroleum jelly to discourage ants.

The 3 x 6 inch cylindrical cages were used exclusively in aerial fog tests in 1962 and in most of the fog tests in 1963–64; however, the flat cages were also used in some of the latter tests. Where the wire cylinders were used, they were placed on wooden stakes at 1 inch or 6 feet above ground level, or both.

Approximately 25 female mosquitoes of each species were put in separate cages and placed side by side in the test plots. The tests were conducted in Indian River County in plots of about 40 to 100 acres in size and similar in flora and physical features to habitats characteristic of the Tampa Bay area. Treatments were ap-

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plied either during early morning or late afternoon.

In the majority of the tests, cages were placed at stations spaced 50 feet apart along lines about 300 feet apart near the center of the plot. Twelve to 24 cages of each species (300 to 600 mosquitoes) were used per test, except in a few instances where only 6 cages were used. Complete plot coverage, flown on marked flight centers, was used for all spray tests and for most of the fog tests. In some of the fog tests, only 2 to 3 swaths were applied upwind of the cages. The same plots and stations were utilized both for aerial sprays and fogs. Mosquitoes were moved to clean cages in the field immediately after exposure to sprays and after approximately one hour exposure to fogs. Cages were held over night in the laboratory and covered with cotton pads saturated with sugar water. Mortality counts of female mosquitoes only were made 24 hours after treatment.

Thermal aerosols were produced by injecting oil solutions of insecticides into the exhaust system of the plane's motors (Salmela, *et al.*, 1960). A 220 h.p. Stearman and a DC-3 airplane were used for the fog tests. In 1963, a 450 h.p. Stearman airplane was used for all spray tests. This airplane was equipped with No. 37 drill-size nozzles having a spring-loaded flap cover against which the insecticide was sprayed at 20 p.s.i. All spray tests in 1964 were conducted with a 220 h.p. Stearman equipped with No. 24 drill-size, hollow-cone nozzles operated at 20 p.s.i.

Insecticide formulations for all spray tests were made by diluting oil soluble concentrates in No. 2 diesel oil. Ten percent to 100 percent of "fog" oil[2] was used in the thermal aerosol formulations except in two tests where diesel oil was compared with "fog" oil.

Samples of the particles in the thermal aerosols and sprays were taken on glass slides coated with magnesium oxide. Thermal aerosol particles were also sampled with a cascade impactor.

RESULTS. Table 1 summarizes results of aerial spray tests conducted in 1963. In hardwood forests of average growth density on the East Coast of Florida, naled at a dosage of 0.1 lb. per acre in 4 quarts volume per acre gave excellent control of both species of mosquitoes when wind velocities at an elevation of 40 feet were about 4 m.p.h. Malathion at 0.4 lb. and fenthion at 0.1 lb. per acre were less effective even in 6 quarts volume; the kill of *Culex nigripalpus* in this plot was especially poor with malathion and fenthion. Naled at 0.1 and 0.15 lb. per acre was less effective in a similar forest plot having very dense growth, even when applied in 6 quarts volume per acre. In a swamp of red maple trees having a dense upper story with sparse understory, naled gave good kills of both *Aedes* and *Culex* at 0.15 lb. in 6 quarts per acre but not at 0.1 lb. in 4 quarts; the latter dosage of naled was effective in dense brush areas having no tree cover.

Results of aerial spray tests conducted with a 220 h.p. Stearman airplane during 1964 are summarized in Table 2. Naled at 0.05 lb. per acre applied in 1 quart volume over a swath of 200 feet killed 100 percent of *Aedes* and *Culex* in open plots having only short grass cover but gave poor results in dense brush and hardwood forest plots. Good kill was obtained in the brush plot with this operation by increasing the dosage of naled to 0.1 lb. per acre.

Malathion gave excellent kills of *Aedes* and good kills of *Culex* in grass plots at dosages of 0.2, 0.3, and 0.4 lb. per acre but was much less effective in brush plots at these dosage rates. No tests were conducted with fenthion in brush and grass plots.

When research with aerial fogs was initiated in 1962, tests were designed to evaluate the effect of the thermal aerosol on adult mosquitoes as it drifted with the wind across the area to be treated, as with ground equipment. Accordingly, test

[2] Sun Oil Co., X-light grade or Standard Oil Co. No. 345 Spray Oil.

TABLE 1.—Results of aerial spray tests against caged adult mosquitoes (*Aedes taeniorhynchus* (Wied.) and *Culex nigripalpus* Theobald) placed at ground level in several habitats in Florida, 450 h.p. Stearman airplane, 80 m.p.h., 1963.[1]

Habitat	Toxicant	Dosage lbs./a.	Volume qts./a.	No. tests	Wind[2] m.p.h.	Temp[2] °F.	Percent kill	
							Aedes	*Culex*
Hardwood forest, average density	naled	0.10	4	2	4	66	98	100
		0.10	4	1	10[3]	70	74	56
		0.10	6	5	5	70	93	97
		0.15	6	3	4	74	91	99
	malathion	0.30	6	2	3	77	89	61
		0.30	6	2	12[3]	75	59	26
		0.40	6	2	2	71	89	61
	fenthion	0.10	6	3	5	72	77	55
Hardwood forest, very dense	naled	0.10	6	5	1	74	82	89
		0.15	6	4	1	77	79	76
Red maple swamp, very dense canopy	naled	0.15	6	3[4]	2	73	99	99
		0.1	4	2	3	71	57	81
Brush (palmetto-gallberry)	naled	0.10	4	2	3	71	99	94
		0.15	6	3	3	74	98	100

[1] All tests flown on marked swaths 100 feet wide.
[2] Average wind velocity at 40 feet and average temperature at 6 feet above ground.
[3] Included to show effect of high winds on kill.
[4] Only one test with *Aedes taeniorhynchus*.

TABLE 2.—Results of aerial spray tests against caged adult mosquitoes (*Aedes taeniorhynchus* (Wied.) and *Culex nigripalpus* Theobald) placed at ground level in several habitats in Florida, 220 h.p. Stearman airplane, 80 m.p.h., 1964.

Habitat	Toxicant	Dosage lbs./a.	Swath (feet)	Volume qts./a.	No. tests	Wind[1] (m.p.h.)	Temp[1] °F.	Percent kill	
								Aedes	*Culex*
Short grass (no cover over cages)	naled	0.05	200	1	3	5	79	100	100
		0.1	200	1	5	5	79	100	100
		0.1	100	2	3	5	75	100	100
	malathion	0.4	100	2	2	5	..	100	82
		0.3	200	1	1	5	76	100	90
		0.2	200	1	1	6	79	98	88
Brush (palmetto-gallberry)	naled	0.05	200	1	3	5	79	72	61
		0.1	200	1	5	5	79	95	97
		0.1	100	2	3	5	75	95	98
	malathion	0.4	100	2	2	5	..	77	31
		0.3	200	1	1	5	76	64	26
		0.2	200	1	1	6	79	45	10
Hardwood forest, average density	naled	0.05	200	1	2	4	..	68	50

[1] Average wind velocity at 40 feet and average temperature at 6 feet above ground.

TABLE 3.—Results of aerial fog tests against caged adult mosquitoes (*Aedes taeniorhynchus* (Wied.) and *Culex nigripalpus* Theobald) in Florida, 220 h.p. Stearman airplane, 1962–64.

					Percent kill							
		Swath			Cages 6 feet above ground				Cages at ground level			
					Bare ground		Trees		Bare ground		Trees	
Toxicant	Formulation-Volume[1]	width (feet)	No.	No. tests	*Aedes*	*Culex*	*Aedes*	*Culex*	*Aedes*	*Culex*	*Aedes*	*Culex*
Malathion	10.0–150	100	c	1	..	..	52	4	..	..	15	2
	8.0–320	330	3[2]	8	97	..	..	..	..	..	..	..
	8.0–320	300	c	1	..	..	9	3	..	..	10	1
	8.0–320	100	c	7	..	..	51	19	..	..	26	9
	8.0–320	100	c	3[3]	..	..	86	70	..	..	66	37
	5.3–600	100	c	1	..	..	..	..	98	96	30	13
	9.0–600	100	c	1	..	..	..	38	..	..	53	31
Naled	3.0–150	330	2[2]	4	68	38	..	..	40	12	..	..
	3.0–650	330	3[2]	1	96	100	..	..	89	73	..	..
	3.0–150	330	c	1	100	100	..	..	100	100	..	..
	1.4–320	330	3[2]	1	100	100	..	..	100	99	..	..
	1.4–320	330	c	1	100	100	..	..	100	90	..	..
	1.2–600	100	c	1	..	..	68	55	..	..	48	43

[1] Gals./100 of malathion 90 or naled 14—volume in gals./hour.
[2] All swaths upwind from cages; cages 165 and 330 feet from last swath.
[3] Orange grove; all other data for trees indicate dense hardwood forests.
[c] Complete plot coverage.

cages were exposed above ground level in a manner similar to that used by Davis, *et al.* (1960). However, it was soon recognized that aerial applications normally are made during daylight hours when mosquitoes are at rest, whereas ground equipment is used at night when mosquitoes are in flight. In the case of both species used in these tests, the mosquitoes rest on the ground during daylight hours; therefore, in order for test results of aerial applications to be meaningful against these species it was necessary to place test specimens at ground level, which is where natural populations are when aerial applications normally were made. This is especially important when the poor deposit characteristics of aerosol-size particles are considered. Consequently, test results shown in Tables 3 and 4 reflect the effects of cage position and habitat as well as operational factors on mosquito kills with aerial fogs.

Usually, only one fog test could be conducted in a single day; therefore, when test conditions appeared to be good and results were unsatisfactory, a change was made in formulation, volume, or equipment before the next test. This procedure resulted in the large number of single tests included in Tables 3 and 4.

Results show that in general the kill with fogs was related more to cage position and habitat cover than to formulation, volume, or swath. With few exceptions, mosquito kill with fogs was very good where cages were located on bare ground, both at ground level and at 6 feet above ground, regardless of insecticide or operation. However, where cages were positioned in brush and dense tree growth, results were consistently poor. It is also of interest to note that kills of *Culex nigripalpus* in wooded plots with aerial fogs were generally much lower than for *Aedes taeniorhynchus*. Mosquito kill with aerial fogs at ground level in brush plots generally were intermediate between those for bare ground and tree plots.

There was no difference in results of tests comparing diesel oil and "fog" oil as diluents, so these tests were not treated separately in Table 3.

There was an overlap in the size of particles of sprays and fogs sampled in this study. The data in Table 5 are from glass microscope slides placed in open areas and under tree cover in hardwood forest plots during spray and fog tests. The numbers of particles shown are those counted on one complete traverse near the center of the slide along the long axis. When the number of particles and their average diameters for the fog tests at 320 and 600 g.p.h. are compared with corresponding figures for the spray tests at 6 quarts per acre, at comparable wind velocities, the data appear quite similar. However, in samples taken with a cas-

TABLE 4.—Results of aerial fog tests against caged adult mosquitoes (*Aedes taeniorhynchus* (Wied.) and *Culex nigripalpus* Theobald) in Florida with a DC-3 airplane; air speed 125 m.p.h., 1200 gallons per hour—1963.

		Percent kill							
		6 feet above ground				Ground level			
		Bare ground		Trees		Bare ground		Trees	
Toxicant	Formulation-Swath[1]	*Aedes*	*Culex*	*Aedes*	*Culex*	*Aedes*	*Culex*	*Aedes*	*Culex*
Malathion	4.5–300[2]	100	99	12	14	100	96	6	5
	8.0–[3, 4]	..	..	14	10	..	..	2	2
Naled	1.0–200[4]	..	..	..	..	100	97	..	..

[1] Gals./100 of malathion 90 or naled 14—swath in feet.
[2] Two tests bare ground, one in trees.
[3] Swaths variable, not marked.
[4] One test only.

TABLE 5.—Deposits of insecticidal particles of aerial sprays and thermal aerosols on glass slides coated with a film of magnesium oxide.

	Type plane	No. of Tests	Avg. wind speed at 40 feet (m.p.h.)	Volume (qts./ a. or gal./hour)	Swath (feet)	Type of cover	Avg. No. particles per slide[1]	Percent reduction under cover	Avg. diameter
Spray	450 h.p. Stearman	9	1	6 qts.	100	none	55	..	84
						forest	24	58	56
		12	4	6 qts.	100	none	96	..	89
						forest	28	71	74
	220 h.p. Stearman	10	6	1 qt.	200	none	9	..	91
		4	5	2 qts.	100	none	17	..	95
Thermal aerosol	220 h.p. Stearman	1	4	150 g.p.h.	100	none	45	..	17
						forest	22	51	22
		3	4	600 g.p.h.	100	none	77	..	50
						forest	22	71	33

[1] Corrected figures based upon slides exposed an equal length of time prior to treatment.

TABLE 6.—Particle size of thermal aerosols produced by a 220 h.p. Stearman airplane discharging 320 gallons per hour as sampled by a Cascade Impactor.

No. of tests	Approximate altitude of flight (feet)	Distance of sample from plane (feet)	Wind speed at 40 feet alt. m.p.h.	Percent of particles in indicated size range (microns)				
				<1	1–5	6–10	11–20	>20
2	60	Under plane	1	99.48	0.59	0.06	0.01	0.02
1	15–20	50	5	98.35	1.48	0.08	0.60	0.00
1	15–20	165	5	96.98	2.42	0.48	0.09	0.00

cade impactor, more than 90 percent of the particles in the aerial fogs were smaller than 5 microns (Table 6). Particles in this size range will not deposit in sufficient numbers on slides to give valid samples; therefore none are shown in Table 5.

Discussion. These tests show that habitat was an important factor affecting results and that there was no single spray operation which was effective in all mosquito habitats, except possibly the operation required by conditions imposed by those plots having the greatest density of plant growth. While malathion sprays gave good kill of both *Aedes* and *Culex* in relatively open areas, of the insecticides and operations tested, naled sprays appear to offer the best prospects for providing fast, effective control of *Culex nigripalpus* in the principal habitats of this encephalitis vector in Florida.

It has been known for many years that true aerosol-size particles do not deposit well on the ground (Yeomans, 1950) and therefore are effective primarily in space treatments. In the case of adult mosquitoes, this indicates application at night during the activity period of these insects.

Use of the thermal exhaust principle for atomizing DDT solutions with aircraft for control of anopheline larvae has been reported by several workers (Kruse and Metcalf, 1946; Magy, 1949); however, a study of these data shows that these operations produced particles up to 200 microns or larger in size. Most of the earlier reports refer to these operations as "thermal aerosols," but Sebora, *et al.* (1946) used the term "exhaust-generated sprays," which seems more descriptive.

Lindquist, *et al.* (1945) used the thermal exhaust method for applying DDT against adult *Aedes taeniorhynchus* in Florida, discharging a volume of 2 quarts per acre from an L-4B Cub airplane. A test with 5 percent DDT was a failure. Another test using 20 percent DDT gave good results, but the authors expressed the opinion that the greatest kill was obtained with the spray-size particles in the "smoke-spray." Tests with DDT sprays (5 percent at 2 qts./acre) in this series were reported to be generally successful. Present evidence, therefore, seems to indicate that the thermal-exhaust principle of applying insecticide solutions with aircraft for control of adult mosquitoes is not an efficient operation.

Likewise, conventional airplane sprays, while effective, must also be regarded as inefficient because of the large percentage of the insecticide that is prevented from reaching the ground by impingement on plants in wooded areas (see Table 5).

The authors are in agreement with Lewallen (1962) that there is a great need for development of equipment and procedures designed specifically for vector control with aircraft, present operations being mostly an adaptation of those that were developed for control of agricultural pests. A dispersal system that will produce particles only in a size range suitable for penetration of foliage and deposit on the ground appears to be one of the more desirable objectives for development work with aircraft. Recent reports of low-volume concentrate sprays against grasshoppers (Messenger, 1963) and the cereal leaf beetle (Wilson *et. al.*, 1965) appear to be a step forward toward this objective.

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COMPARATIVE TESTS OF FOG OILS AND DIESEL OIL AS THERMAL AEROSOLS FOR CONTROL OF ADULT MOSQUITOES

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The possible effects of the use of oils of high viscosity in thermal aerosol formulations have been realized for some time. Peterson (1952) using fuel oil, SAE 10 and SAE 50 motor oils in a thermal aerosol generator found that at the same discharge rate an oil of lower viscosity would produce a smaller particle size. In tests conducted by Brown and Watson (1953) with a TIFA aerosol generator, a solution of 5 percent DDT in fuel oil (viscosity 38.7 SSU at 70° F.) produced a smaller particle size (17 μ mmd) than a solution of 30 percent DDT in methylated aromatics (viscosity 44.6 SSU at 70° F.) (26 μ mmd). There was, however, no difference in the biological effectiveness between the two solutions when applied at the same dosage of DDT.

Results of research by Brown and Morrison (1955) show that a formulation of 5 percent DDT in kerosene emitted from a Dyna-Fog Jr. produced a smaller particle size (8.9 μ mmd) than a formulation of 5 percent DDT in fuel oil (18.5 μ mmd), the fuel oil being of higher viscosity than the kerosene. No comparative tests of the biological effectiveness were conducted. Morrill and Wesley (1955) comparing several fog formulations applied by non-thermal and thermal generators demonstrated an increase in particle size when 20 percent SAE 50

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