AN EXAMINATION OF UNITED STATES AIR FORCE AERIAL SPRAY OPERATIONS

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INTRODUCTION. The United States Air Force has engaged in aerial spraying since the inception of the technique. In 1923–24, aerial dusting was undertaken at Mound, La., and in 1927, Quantico, Va., was dusted (Lumpkin & Konopnicki, 1962). The Air Force has conducted extensive worldwide aerial spray operations since the latter part of World War II. Development of equipment and techniques was undertaken, using liquid DDT, with the Department of Agriculture at Orlando, Fla., in 1943 (Lumpkin & Konopnicki, 1962). In 1945, large areas of the Philippines were aerially sprayed for mosquito and house fly control (Lumpkin & Konopnicki, 1962). In 1946, the Special Aerial Spray Flight was organized and has since operated in the continental United States, Alaska, Labrador, the Bahamas, Iran, and Afghanistan (Anonymous, 1959, Nowell 1955a and 1955b, Lumpkin & Konopnicki, 1962, Dowell, 1962). An extensive aerial spray program was undertaken by 5th Air Force in Korea in 1951 (Nowell, 1955).

A variety of different liquids, dusts and granular materials have been dispersed using widely different equipment and conceptions of operation. L-5's, L-20's, C-47's, and C-123's fitted with equipment such as straight emission pipes, rotary wire brushes, commercially procured granular dispensers and pressure boom and nozzle liquid systems have been used (Nowell, 1956a and 1956b, Lumpkin & Konopnicki, 1962, and Dowell, 1962). While some bases and other Air Force organizations have maintained their own aerial spray equipment, the major part of this work has been done by the Special Aerial Spray Flight (SASF), Tactical Air Command, (TAC), Langley AFB, VA. (Anonymous 1959 & 1960b). This organization has supplied services for the Army, Navy, Air Force, and other federal agencies. These services included mosquito, Japanese beetle and fire ant control (Anonymous 1959 & 1960b).

THE PROBLEM. While the activities mentioned above generally have been effective, there has been considerable dissatisfaction with the overall organization of the program (Lumpkin & Konopnicki, 1962, and Dowell, 1962). In particular, it was suspected that there was considerable duplication of effort and that in many cases equipment and personnel were not being used in the most effective and economical manner (Anonymous, 1959). Also, there was the distinct possibility in some cases of lack of effectiveness (Anonymous, 1959).

Therefore, beginning in 1959, an extensive review of every aspect of aerial spraying by the Air Force was undertaken (Anonymous, 1960a). Questions to be answered by this review were: (1) *Policy*: It appeared to be fragmented, with no one particularly in charge. More and more insecticide was being dispersed over ever-expanding areas. What changes were necessary? (2) *Capital Investment*: What amounts of and in what ways should investment be made in new equipment in order to insure effective, efficient and safe application? (3) *Suitability of Aircraft Types*: Were the best types of aircraft being used, or were they the best because they were being used? What compromise could be reached between

The opinions expressed herein are those of the author only and do not necessarily reflect those of the United States Air Force. Parts of this paper have appeared in five published papers and five Air Force Reports. The purpose of this paper is to bring this information together in one available place.

desirability and availability? (4) *Effectiveness of Equipment*: Were the systems available actually doing the physical job for which they were designed? (5) *Biological Effectiveness of Systems*: Were these systems, if they were or were not functioning as designed, actually controlling insects?

Cooperating with Tactical Air Command in this project were the USAF Epidemiological Laboratory, U.S. Army Environmental Hygiene Agency, U.S. Navy Disease Vector Control Center, Jacksonville, the U.S. Department of Agriculture Laboratory at Orlando, several mosquito abatement districts and numerous individual service and civilian entomologists and technicians.

In general, it was determined (Anonymous 1960a) that there was room for improvement in all of the above areas. In particular, the areas of equipment, aircraft types, and concept of operations needed extensive thought and development. This detailed evaluation showed that the original appreciation of the situation had been correct. With no one actually in charge, there had been a slow, progressive increase both in areas covered and deposition rates for 13 years, until its justification could be questioned. As an immediate solution to this questionable increase, while evaluation continued, all marginal projects were cancelled. This produced an immediate 50 percent reduction in area covered.

Two points were apparent concerning policy. First, there was a lack of clarity concerning objective. Aerial spraying was being used to avoid the possible accusation of negligence, as well as to protect people and property. Naturally, this caused extensive over-use. The basic problem appeared to be a separation of management and operation from science and technology. Second, the equipment being used accentuated the problem of over-use. It was all quite old, yet still worked. This led to the feeling that reexamination of equipment capabilities was no longer necessary. Consequently, as the workload increased for the reasons given above, this workload was stabilized by limitation of operations to a specific geographical area rather than producing equipment that could handle the higher workload. This geographical limitation in turn produced excessive utilization within the geographical area in order to maintain this artificial work level and extensive "bootlegging" of aerial spraying outside of the specified area using inadequate equipment and untrained personnel. This closed pattern of inevitably increasing total workload and lessening effectiveness, once established, continued in the absence of any positive external control.

In the area of new capital investment, it was determined that all existing aircraft and equipment should be replaced by six C-123 aircraft with spray systems designed to disperse liquids, dusts and granules. Less aircraft cost, this would require an estimated $300,000.

In relation to types of aircraft, the L-20's and C-47's being used were doing the job for which they were designed. However, they were in the process of being phased out of the TAC inventory and their limited capacity and range restricted their operations. As mentioned above, this tended to produce over-use and "bootleg" operations.

The techniques and procedures being used, a combination of Porton and curtain spray methods, were basically sound. Ground marking methods, however, restricted use to areas immediately adjacent to airfields, etc. Consequently, the aircraft were not being used even to the extent of their limited capabilities, but were restricted by the marking method employed. There appeared to be some lack of understanding of the nature of an airplane. Essentially, they appear to have been viewed as expanded trucks. Actually there is a quantum advance involved. Aircraft are sufficiently different from trucks so as to require different ideas of employment.

The spray equipment of the C-47, while limited to liquids only, did what it was supposed to do physically. The L-20 (granular) equipment was hopelessly inadequate because of limited capacity, narrow swath width and variable deposition rate. Apparently, it was being used only because it was available.

An extensive biological evaluation of the effectiveness of aerial spraying with liquids was conducted at Ft. Stewart, Ga., Dover Air Force Base, Del., Cannon Air Force Base, N.M., various locations in Florida, and Eglin AFB, Fla. Tables 1 and 2 (Fowler *et al.*, 1961) give the results from Ft. Stewart, Ga. Table 3 (Fowler *et al.*, 1961) gives the results from Dover AFB, Del. Table 4 (Parrish and Hodapp, 1962) gives the data from Cannon AFB, N.M. Table 5 (Anonymous, 1960) shows the results from the Florida sites. Tables 6 and 7 (Hodapp, Parrish and Dowell, 1962) give the results of the tests at Eglin AFB, Fla. Because of equipment limitations and inadequate formulation standards, it was impossible to begin to evaluate the biological effectiveness of the granular dispersal system.

TABLE 1.—Mosquito larval[a] counts in areas of sparse ground vegetation during aerial spraying[b] test at Ft. Stewart, Georgia, 1960.

Date		Larval Index[c]		
		Untreated Zone	Treated Zone	Percent Reduction
August	3	6	6	0
	4	5	6	0
	5	6	7	0
	6	5	9	0
	7	..	..	..
	8	9	5	45
	9	8	3	62
	10	7	4	43
A. Spray	11	7	0.1	98
	12[d]	7	0.1	98
	13	5	1	80
	14	6	1	84
	15	6	2	67
	16	5	2	60
	17	8	2	75

[a] *Aedes atlanticus, A. mitchellae, Anopheles crucians, Psorophora confinnis,* and *P. ferox.*
[b] 20 percent DDT in a fuel oil base.
[c] Average of 10 dips.
[d] Rainfall of sufficient quantity to flood breeding sites.

TABLE 2.—Mosquito[a] landing counts in areas of sparse vegetation during aerial spraying[b] at Ft. Stewart, Georgia, 1960.

Date		Landing Counts[c]		
		Untreated Zone	Treated Zone	Percent Reduction
August	3	37	34	8
	4	47	44	0
	5	39	42	0
	6	42	44	0
	7	..	..	..
	8	36	39	0
	9	61	65	0
	10	46	48	0
A. Spray	11	48	1	98
	12[d]	71	2	97
	13	73	5	93
	14	70	2	97
	15	64	3	95
	16	60	4	93
	17	55	7	87

[a] *Aedes atlanticus, A. mitchellae, A. crucians, Psorophora ferox,* and *P. confinnis.*
[b] 20 percent DDT in a fuel oil base.
[c] Average of 12 stations.
[d] Rainfall of sufficient quantity to flood breeding sites.

The above tables show, as would be expected, that the C-47 liquid spray system was effective for larviciding where there is little cover and for adulticiding where there is little cover. However, Table 5 shows that it was also very effective for adulticiding in jungle. Using oil sensitive dye cards, the mass median diameter of the particles produced by this system is 150 μ. These cards will not register particles under 40 μ in size. At all of the jungle stations oil sensitive cards were in place, no particles were registered, yet excellent kills resulted. From this it was concluded that the fraction (under 5 percent by volume, 0–40 μ) of the particle size spectrum that goes to make up a mass median diameter of 150 μ that could, because of lack of impingement on leaves, penetrate jungle canopy, was penetrating this canopy. This would explain both the lack of registration on the cards and the adult mosquito kills.

From these tests it was concluded that the granular dispersal system was so inadequate that testing would be useless.

TABLE 3.—Mosquito[a] landing counts during aerial spraying[b] at Dover AFB, Del., 1960.

Date		Landing Counts[c]		
		Untreated Zone	Treated Zone	Percent Reduction
June	3	92	37	60
	4	87	31	64
	5	73	41	44
	6	66	60	9
A. Spray	7	52	20	62
	8	63	24	62
	9	71	29	59
	10	70	19	73
	11	80	26	67
	12	Heavy rainfall—study terminated		

[a] *Aedes sollicitans and Culex salinarius.*
[b] 7 percent malathion in a fuel oil base.
[c] Average of 17 stations.

The liquid dispersal system was effective for both adulticiding and larviciding but inefficient for adulticiding. All available evidence pointed to the desirability of mobility, flexibility, minimum use of material, precise particle size control, exact deposition rates, large area coverage, long range, high capacity and the specialized role (limited but essential) of dusts, granules, and baits.

APPLICATION OF THE PRINCIPLES OF AIR POWER AND MILITARY ORGANIZATION TO THE PROBLEM. After examination of the results of the evaluation given in detail above, the conclusion was reached that all of the very real deficiencies that had been found were symptoms of a larger problem—the lack of a rational, unified concept of aerial spray operations (Dowell, 1962). Any attempt to solve peripheral problems without getting at this central issue would only waste time and cause, as it has in the past, needless confusion. It was also felt that this necessary concept could best be developed by testing the problem against known, established principles of air power and military organization. For instance, some of the principles of air power that are included in the Tactical Air Command Composite Air Strike Force concept are mobility, flexibility, concentration of force, and economy of effort. All of these principles, developed over more than five decades, would seem to be as applicable to aerial spraying as to fighter operations. For, once specialized technical requirements are met, most aircraft operations are basically similar. With control of the aircraft there is control of the operation. In addition, it was felt that, in large measure, many of the problems encountered were the result of the violation of the four principles of military organization: homogenous assignment, span of control, unity of command, and delegation of authority.

A NEW CONCEPT OF OPERATION. Against this background of known discrepancies and established principles, it was decided to establish a concept of aerial spraying in accordance with tested policy and procedures (Dowell, 1962). It was to be par-

TABLE 4.—Mosquito[a] landing counts during aerial spraying[b] test at Cannon AFB,[c] N. M., 1960

Date		Landing Counts[d]		
		Untreated Zone	Treated Zone	Percent Reduction
June	17	27	17	37
	18	32	15	53
	19	30	16	47
	20	28	16	43
	21	26	15	42
	22	27	16	41
	23	29	18	38
A. Spray	24	28	4	86
	25	27	1.3	96
	26	26	1	96
	27	35	5	86
	28	36	2	94
	29	35	1	97
	30	35	3	91
July	1	34	1	97
	2	33	1	97
	3	31	0.5	98
	4	29	0	100
	5	28	0	100
	6	25	0	100
	7	25	0	100

[a] *Aedes nigromaculis, A. vexans, A. dorsalis,* and *C. tarsalis.*
[b] 7 percent malathion in a fuel oil base.
[c] Continuous ground control program during test.
[d] Average of 15 stations.

TABLE 5.—Results of field tests with aerial sprays applied with a C-47 airplane against salt marsh mosquito adults (predominantly *Aedes taeniorhynchus*).

Insecticide	Dosage (lb./acre)	County and Plot	Pretreatment Count[a]	Percent Mortality After 3 Hr.	6 Hr.	24 Hr.
Malathion	0.25	Sarasota: Venice Jetty	6	55	87	84
		Lee: Captiva Island	36	43	77	85
		Brevard: Allenhurst	80	87	90	64
	.1	Sarasota: Venice Airport	11	92	93	50
		Lee: Sanibel Island	24	98	98	82
		Brevard: Shiloh	71	98	98	43
		Average				
Malathion	0.25		41	62	85	78
	.1		35	96	96	58

[a] Number per man per minute.

ticularly tailored to military requirements. It was not to be a perhaps unwarranted imitation of commercial agricultural operations.

First, there would be a rationale. From this would be developed in turn policy and procedures. Then the equipment and techniques necessary to implement this policy, through the procedures established, would be devised.

As the rationale behind military aerial spraying, it has been definitely established in over 16 years of extensive operations that there is a continuing requirement for worldwide aerial dispersal of a number of different materials (liquids, dusts, granules, and baits) for many different purposes (routine pest control, medical and other emergencies, vector control in tactical situations and special projects). Further, most of this work has been of a large area, high capacity nature. As the same equipment and techniques can, with

TABLE 6.—Pre- and post-spray larval counts—Test Area No. 1 (Eglin AFB, Florida).

Station No.	Larval Rates (Pre Spray) (Total/10 Dips)	Larval Rates (Post Spray) (Total/10 Dips) 14 Hrs.	20 Hrs.
1	51	62	67
2	37	35	36
3	15	14	15
4	12	11	12
5	7	7	6
6	10	12	14
7	6	6	6

TABLE 7.—Pre- and post-spray larval counts—Test Area No. 2 (Eglin AFB, Florida).

Station No.	Larval Rates (Pre Spray) (Total/10 Dips)	Larval Rates (Post Spray) (Total/10 Dips) 14 Hrs.	20 Hrs.
1	350	350	352
2	240	240	234
3	10	1	0
4	3	2*	3*
5	25	24	26
6	27	30	25
7	2	1*	1*

* Pupae.

minor modification, be used for all purposes, it was logical to assume that Air Force commitments could best be met by centralized, mobile, multipurpose equipment operating under standardized policies and procedures.

From this, it was decided that Air Force policy would be to undertake high capacity aerial spraying for all purposes, worldwide, for all agencies of the Department of Defense and other government agencies on request. This mission was delegated to TAC and in turn to SASF. This organization, under positive control, would be mobile, flexible and standardized. Integral technical monitoring would be provided. Air Force Regulations have been revised to reflect this policy.

The procedures by which this policy would be carried out would be, first, a regular program of routine pest control (under close technical supervision) as a means for meeting routine high capacity requirements, development and testing of equipment and techniques, and maintenance of aircrew proficiency. A mobility posture would be maintained for emergencies and overseas deployments. Supplementary air crews, maintenance personnel, and airlift could be drawn from TAC and Air Force resources, as required, in accordance with an established, current operations plan. At all times appropriate technical monitoring would be provided by assignment or attachment of specialists. As all requests for routine control would have to be forwarded to TAC for review and approval, yearly evaluation of each program would be insured and workload could be adjusted to available resources on a rational basis. Deployments and emergencies would, of course, be handled on a call basis. If necessary, routine work could be slipped.

If the items above were to be accomplished, the existing aircraft (C-47, L-20) of SASF were inadequate. Also, the equipment being used was not modern and could be greatly improved. One of the basic problems was that the C-47 could not be readily modified to disperse granular materials. This forced the L-20 to accept a mission for which it was totally unsuited because of short range and low capacity. After careful study, it was decided that the C-123 best met the requirements for the mission in that it was simple, rugged, could be modified to disperse all types of materials, could perform the necessary maneuvers, could, with minor modification, be deployed anywhere, was in the current Air Force inventory and was available (Anonymous, 1960c). It was neither so expensive nor so scarce that it was hopeless of diverting from squadron service.

From the decision to use the C-123 was derived the design of the dispersal systems (Anonymous 1960c). These basic configurations were envisioned: a single 1000-gallon tank mounted at the center of gravity for use with any heavy liquids, two 1000-gallon tanks mounted in tandem for high-capacity work with light liquids and a multi-purpose installation of a 10,000-pound capacity hopper mounted forward and a 1000-gallon tank mounted aft, either of which could be filled while the other was installed, but empty. In all cases, the liquid tanks would be part of the long range fuel system. The 1000-gallon liquid module would consist of a baffled tank, gasoline engine driven centrifugal pump, controls, the hardware necessary for recirculation and emergency dump and boom mounted T-Jet nozzles and swivels with rapid shut-offs and interchangeable tips and cores. Deposition rates of up to 3 gallons per acre and particle size variation from 50 to 220 μ mass median diameter were envisioned. The granular system would consist of a 10,000-pound capacity, gravity flow hopper (with agitation as necessary) feeding into a bifurcated, "Swathmaster," perforated air foil, spreader. Provisions would be made for an integral mechanical loading device and emergency dumping.

The techniques by which this equipment would be used would be basically the same as those prescribed in AFM 90–4. These would be conventional crop dusting patterns, but at a standard altitude of 150 feet. Curtain spraying would not, of course, be possible. The principal difference would be that the speed, range and capacity of the C-123 could be used to compensate for the difficulty of transporting, mixing and loading materials in inaccessible areas. This ability to operate from a central facility 300–500 miles from the area being sprayed (independent of ground marking because of the use of precise navigational techniques) would be of considerable value in tactical operations and in primitive areas where there are limited support facilities. After all, the ability to operate (or rather the necessity for operating) immediately adjacent to the area being sprayed is not so much a positive advantage as it is an expression of design limitation.

TESTING THE NEW CONCEPT. This new unified concept of aerial spraying (maximum, effective, efficient, safe utilization of the capabilities of existing aircraft made possible by proper equipment and realistic procedure) was tested in a variety of different ways using the principle of concurrency wherever possible (Dowell, 1962). First, maximum use was made from the information gained from the C-47 and L-20 systems evaluation. Second, as the C-123 liquid system, designed to eliminate difficulties encountered with the L-20 and C-47, became available, it was subjected to intensive calibration and service test while the granular system was being engineered. It proved to be a particularly trouble-free and versatile unit. It is now being used in routine pest control work. A detailed biological evaluation of all of its capabilities continues. Third, command, control and mobility procedures were tested in two actual situations: Hurricane "Carla" in 1961, and locust control in Iran and Afghanistan in 1962. In all of these operations, the concept of operations, equipment and techniques was found to be basically sound. In particular, the navigational techniques mentioned above were found to be indispensable. In Iran and Afghanistan, locust control operations were carried out successfully up to 500 miles from the only available sources of support. Without the range, capacity and speed of the C-123, and our new navigational procedures, these operations simply could not have been accomplished.

It should be emphasized that this concept of operations has worked well with existing Air Force communication and direction systems. In one two-month period in 1962, a specific C-123 was deployed completely around the world, conducted extensive, diverse operations in the process, and returned to routine pest control in the United States without incident. While there have been problems, none of them have been insurmountable. Most important, there have been no clashes of basic doctrine. Air Force aerial spray operations are now fully integrated into the existing Air Force command and control system and are being conducted with a minimum of difficulty.

THE PRESENT SITUATION. At present, SASF has three C-123's modified for liquid dispersal. Four C-123's modified for liquid and granular dispersal have been delivered and are in service test. The potential of both systems is being examined. A nucleus of trained, experienced aircrews exists. Finally, a sound, compatible, unified concept of operations has been tested and accepted.

SUMMARY. A unified concept of aerial spraying has been developed based on existing Air Force doctrine. The main elements of this concept are centralization, mobility, flexibility, and integral technical monitoring. The selection of aircraft types, design of equipment and development of techniques have been in accordance with these principles. In practice, this allows the United States Air Force to bring a tailored aerial spray force to bear anywhere for any purpose within 7–10 days. This appears to have been a successful application of the known, tested, principles of air power and military management to what is, for the military, an esoteric field.

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CORRECTION

This notice calls attention to an error in the article, "Hosts of Mosquitoes (Diptera: Culicidae) from the irrigated areas of Alberta," by J. A. Shemanchuk, A. E. R. Downe and L. Burgess, Mosquito News Vol. 23, No. 4 (Dec. 1963), page 337. *Culiseta inornata* should be listed last, opposite the present last line of host data; i.e. the last line should read, "*Culiseta inornata* (Williston): 9C, 2P, 2Hu, 1S, 4N." Then each line of "Host" data should be transposed 1 line downward from the present position, so that the order is *Aedes campestris*; 1C, 1P, 1S; *Aedes cataphylla*: 6C, 3P, 4S, 1D, 4N, etc.

We regret this error and hope that this correction will come to the attention of workers who may be interested.