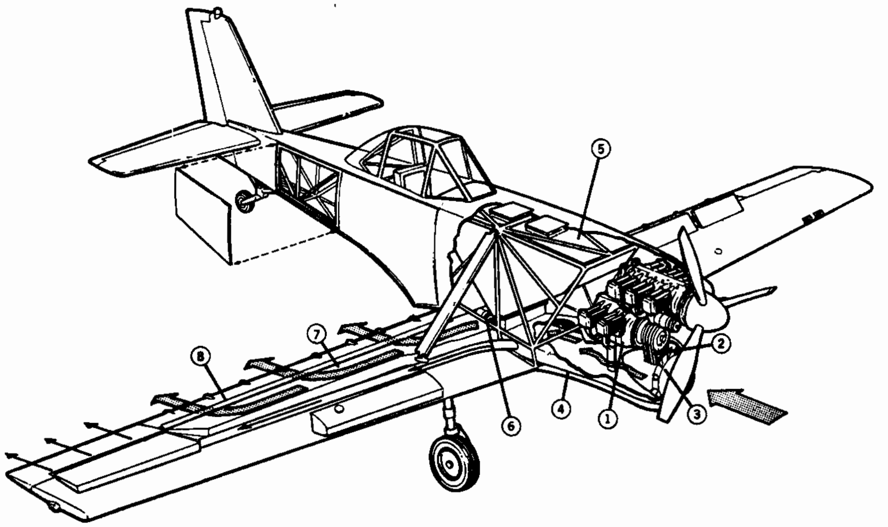
CONTROLLED-DISTRIBUTION WING FOR AGRICULTURAL AIRCRAFT

A new concept for aerial application of agricultural pesticide chemicals, seeds, and fertilizers is now nearing the point of practical application. The concept involves utilization of air forced from the trailing edge of the wing of an aircraft to give boundary layer control of air flow effects on the wing and to entrain and transport dry chemical materials through ducts in the wing and discharge them rearward. The new system offers improvements in application of dry materials by permitting higher application rates per acre, and wider, more uniform material distribution. Research leading toward the development of the "distributor wing" has been conducted for the past five years by agricultural engineers at University of California, Davis, in cooperation with Kenneth Razak, formerly Dean, College of Engineering, University of Wichita, Kansas, who has also developed an aircraft to utilize the new wing.

N. B. AKESSON

W. E. YATES

W. E. BURGOYNE



Diagrammatic sketch of prototype aircraft, above, with controlled-discharge wing, shows second engine (for fan supplying boundary layer control air), wing ducting, and flaps. Actual photo of full-scale prototype of the Razak agricultural aircraft with controlled-distribution wing, below.

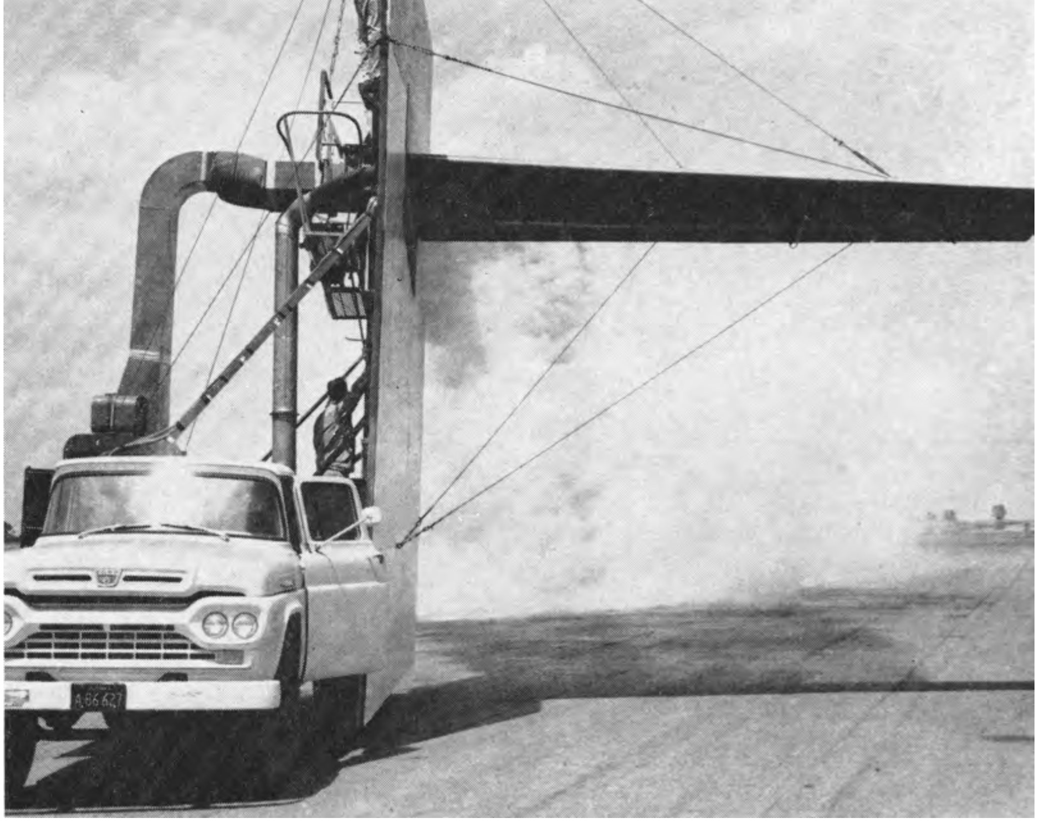
A NEW DISTRIBUTOR-WING aircraft has been developed around the "boundary layer control" technique, which is a well known method of directing additional air to assist in maintaining normal air circulation about the wing of an aircraft, particularly under flight conditions of low air speed and high wing loading. The principle has been adapted to an agricultural aircraft by using a fan to force the boundary layer air through wing ducts and discharge it rearward over the wing flaps and ailerons. This air also serves to entrain and transport dry materials such as fertilizers and seeds. A hopper and controlled feeder places the dry materials in the airstream between the fan and the wing ducts, and then discharges them along the wing span (except for the aileron portion) of the airplane.

Because this air can be controlled in direction and strength along the entire wing span, it offers improvement in dry materials application by allowing higher application rates per acre, and wider and more uniform material distribution. Boundary layer air technique is also particularly useful to agricultural aircraft because it allows greater aerodynamic stability for the slow-flying, heavily loaded airplanes. It also permits shorter take-off and landing distances for given loads—or greater load carrying ability. An engine separate from the propulsion engine is used to drive the distributing air fan. This gives the aircraft an element of two engine safety because the plane receives considerable extra jetlike propulsion from the air ejected through the wing slot. This extra power extends the glide potential in case the propulsion engine fails.

While the controlled-discharge feature is particularly useful for dispensing dry materials, it is also a significant factor in controlling liquid dispersion. The direction and strength of the discharged air carrying atomized liquids can be adjusted to also direct liquids into a more uniform and desirable wide-swath pattern.

Truck mounting

Work on the controlled-discharge wing was begun in 1960 with swath-width and distribution studies using a semi-span model wing mounted on a truck. By 1964 these studies advanced through two models. Many test runs had proven the concept was sound and indicated that a significant advance in aerial application could be made utilizing it in the design of a new aircraft. Kenneth Razak, formerly Dean of the College of Engineering, University of Witchita, Kansas, organized a company for this purpose, and a prototype aircraft, based on the model test program, was test flown in 1965.



Boundary layer control wing mounted on truck, showing the semi-span wing, boundary board and ducting for carrying the boundary layer air and dry materials. Dust is being discharged in this picture.

The first model wing tested was one-third scale, and scale-up variables made it impossible to achieve a similitude of air circulation strength (as displayed by the shed vortex patterns) between model and aircraft to be compared. Thus, a nearly full-scale model was constructed and again mounted on a truck for test purposes. Still, only approximate similitude could be achieved since the model was somewhat smaller than the aircraft and maximum speed was only 60 miles per hour. In use, the prototype plane could be operated from 60 to 120 miles per hour. The table below indicates how other variables need to be considered in order to obtain the basic similitude (between model and airplane) of circulation strength.

Flap and aileron angles were increased significantly on the model to obtain circulation strength comparable with the aircraft. This results in a larger coefficient of lift on the model wing since it is a little smaller than the prototype aircraft wing. To operate the model with these high flap angles, obtaining this coefficient of lift, boundary layer air must be used in order to prevent stalling (stopping of air circulation) of the wing. The air velocity was adjusted on the model to about 25% higher than the forward velocity, or about 80 mph. The air discharge slots were set to 3/8-inch on both flaps and the aileron for the total wing length of 214 inches, giving a total discharge of 3900 cfm (cubic feet per minute).

Conventionally used ram-air spreaders are dependent upon forward velocity of the aircraft to provide the energy needed to discharge and spread the dry materials. Energy transfer in these devices is so low that adequate spreading cannot be achieved. In contrast, the controlled-discharge wing has an engine driven fan to give a positive air flow. This engine and fan must give sufficient air volume and pressure to handle the large volumes of materials and discharge them in uniform and wide swaths.

The total power for the model can be approximated by adding the power required to move the 80 mph air, or about 3 hp, to the 5 hp required to accelerate the 10 lbs-per-second discharge rate of material to 60 mph, the forward velocity of the model. This makes a total of 8 hp.

CHARACTERISTIC COMPARISON OF AIRCRAFT WITH MODEL WING

	Circulation strength (ft^2/sec)	Velocity (miles/hour)	Wing angle (degrees)	Flap angle (degrees)	Aileron angle (degrees)	Coefficient of lift
Aircraft	495	63	13.7	15	0	1.96
Model	495	60	14	30	7	2.59

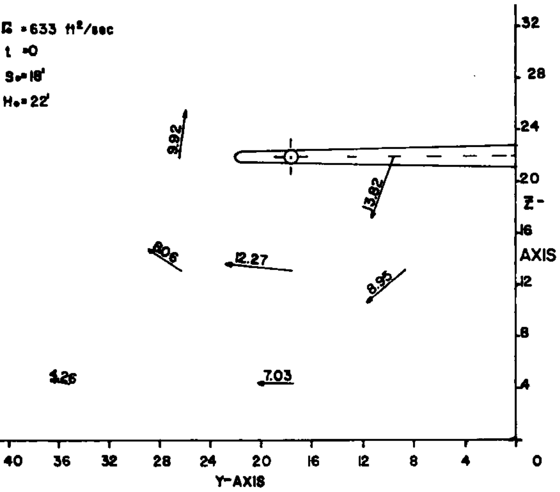
On the full scale aircraft this power becomes 10 hp to move the air and approximately 60 hp to accelerate 45 lbs per second of material to 100 mph forward velocity. This becomes a total of 70 hp for maximum effect. The blower engine on the prototype aircraft is capable of 150 hp and the propulsion engine 300 hp. This should enable the prototype aircraft to spread 300 lbs-per-acre in a 45-foot swath at 100 mph.

Model wing test

Several types of dry materials—granular, prilled, and seeds—have been tested using the full-scale model, as listed below:

Material	Pounds/cubic foot	Approximate length inches
Ammonium sulfate	64	3/32
Prilled urea	45.5	1/16
Rice	38.7	3/16
Granules 10/20	35.4	1/16
Granules 35/80	35.4	1/50

The 6,000-foot runway of the Davis-Winters Airport was used for the test series on the C-D wing because a mile distance was required to get the truck up to top speed. A row of plastic baskets, spaced at one-ft intervals was set perpendicular and adjacent to the runway and materials were discharged as the truck passed the baskets. The materials caught in the baskets were transferred to small



GRAPH 1

plastic bags which were in turn weighed on an accurate balance to find the amount of material in each basket. Runs were made only when the wind velocity was low and as nearly in line with the path of the truck as possible. Data were taken on wind velocity and direction as well as wing and flap angle, blower speed, and air velocity, and certain other aerodynamic information on the wing which was taken from photographs of a pressure-reading manometer board.

Dry materials were discharged from each of six positions along the wing at distances of 1, 4, 7, 10, and 12 ft from the wing root or point of attachment to the truck. The wing is nearly 18 ft in length and was set on the truck to be 20 ft above the ground, a usual height from which dry materials are spread. The air and materials are not discharged from the wing directly rearward, but have a slight outboard angle. In order to separate the effect of this outward discharge from the effect of the vortex or air circulation pattern created by the wing, it was necessary to make two runs for each ejection position. The first, at 5 mph showed the effect of air discharge direction and the second, at approximately 60 mph showed the additional amount of movement of materials caused by air circulation.

The data of graph 3 shows the results of one such pair of runs. The ejection position was 13 ft, the 5 mph run peaked at 13½ ft and the 60 mph run moved the center of the peak to 17 ft. In order to present data from all discharge positions at once it was necessary to plot the center of mass or peak of each of the individual pairs of runs against the discharge or ejection position. An example of this is shown in graph 2, which was for clay granules of 10/20 mesh Tyler screen grade. The straight line across the graph indicates positions of the material peaks if they had fallen directly behind their corresponding ejection position. However, as noted, the air carried the material outward and so the 5 mph curve (X, line) shows material falling about 4 ft farther out, or beyond each ejection station.

A significant effect of the air circulation is seen for the 60 mph (O, line) curve. The circulation centers around an axis located outboard approximately four fifths of the wing span as shown in graph 1. The air and materials are directed largely downward by this circulation from the wing root to about the 10-ft ejection point, and largely outward from the 10-ft ejection point, and beyond the wing tip. Looking again at graph 2 it can be seen that the downward effect (60 mph curve) actually put the granules in the baskets inboard from the corresponding no-circulation (5 mph) curve until the circulation started moving material outward. The curve reflects this increasing outward effect from the 10-foot point and beyond.

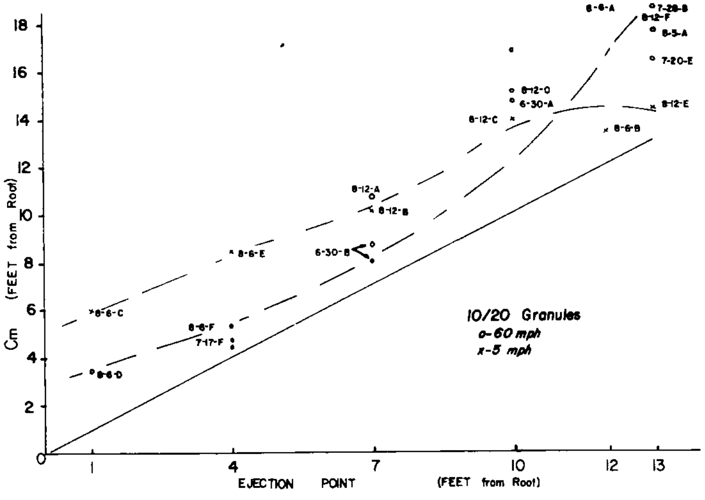
Similar curves were found for other materials such as ammonium sulfate and prilled urea. However, with larger particles such as seeds the two curves lay nearly together indicating that the wing vortex, or circulation, had a lessened effect on large particles as compared with small ones.

The conclusion from the runs is that wing vortex and circulation effects are not sufficient to develop wide swath patterns, particularly with large, heavy particles such as seeds. Hence, the air and materials ejection system must then be utilized to direct the power from the blower into moving the particles outward as well as back for maximum swath widths. Excellent control of the distribution in the swath can be obtained by altering the flow of materials at points along the wing.

The prototype aircraft completed by Razak utilized the principles developed and proven by the truck-mounted model. A number of test runs have been made spreading seeds and fertilizer materials, and results obtained verify the distribution results from the truck-mounted wing. Development of the prototype to a fully commercial stage is presently being undertaken and it is expected that the controlled-discharge aircraft will soon become one of the types of aircraft available for the demanding job of spreading agricultural chemicals and seeds.

Norman B. Akesson is Professor; Wesley E. Yates is Associate Professor; and W. E. Burgoyne is Assistant Specialist, Department of Agricultural Engineering, University of California, Davis. This report is based on research conducted under Project 1423 and supported in part by USPHS Grant 00281.

GRAPH 2



GRAPH 3