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TURBOCLAIR FOG DISPERSAL METHOD: DEVELOPMENT AND TESTING OF UNDERGROUND BLOWER UNIT (1965–1969)

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PARIS AIRPORT
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FINAL REPORT

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16. Abstract

A testing program to evaluate the Turboclair fog dispersal method has been completed at Orly Airport, Paris, France. The program included evaluating underground turbojet engine design and performance, determining the optimum location and orientation of the underground unit relative to a runway, and obtaining data on the unit's functional contribution to fog dispersal. The Turboclair method involves using underground turbojet engines to heat air along runways in order to cause evaporation of water droplets in fog and thus increase visibility. The effectiveness of heat from the engines was evaluated at Orly Airport through air temperature measurements and visual observations.

The results of the test program confirm that the Turboclair method is effective on warm fog when air volumes are heated by the engines to 2°C above ambient temperature. The size of the defogged space is determined by engine orientation as dictated by wind direction and intensity. From test results it is concluded that this type of installation is ready for implementation at an operational level at Orly Airport.

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PREFACE

This Final Technical Report covers results of development and test program carried out from 1965 to 1969.

The program performed by Bertin et Cie at Orly Airport in Paris, France, is discussed in this report by R. Fabre, Research Division, Equipment Section, Orly Airport.

The report forms part of an information exchange program between the Federal Aviation Administration and the French Ministry of Transport. The report was translated to English by Joint Publications Research Service, Department of Commerce, by permission of the Secretariat General a l'Aviation Civile (SGAC) as part of the exchange program under fog dispersal research.

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1. INTRODUCTION

Turbojet engines used in the Turboclair method must be located at a distance from the runway centerline such that they abide by aeronautical regulations stating that no obstacle shall be placed in such a manner as to possibly cause damage to aircraft accidentally deviating from their ground path. Consequently, the turbojets must be located in covered trenches. After verifying the Turboclair method through a series of experiments on a reduced scale using above-ground engines, it was important to design an underground hot-air generator whose characteristics would be similar to above-ground engine characteristics in terms of the dimensions of the air stream. This meant it would be necessary to undertake new testing with two goals in mind: first, determination of the actual hot-air generator design; then, determination of the air volume cleared* by this generator as a function of fog characteristics. An understanding of the distortion of this volume from wind effects is necessary in determining the location and operating program of the turbojets in an operational installation.

The experimental testing and development of any fog dispersal system encounters two major inherent obstacles. The first is the fact that testing is directly related to fog conditions determined by variable weather factors whose effects are difficult to separate. The second is that fog conditions generally cannot be forecast in advance, only last a limited length of time and are of relatively low frequency in respect to experimental requirements. This limits the field of investigation and equally extends the amount of time required to produce the necessary results. Thus, it was important to couple the hot-air generator with experimental methods and means in order to obtain the largest number of results in the shortest length of time while avoiding reliance on actual fog conditions to provide data on the generator's effectiveness.

A test station was constructed at Orly Airport and experimentation was based on air temperature measurements. In effect, a $2^{\circ}C$ increase in temperature is sufficient to provide evaporation of water droplets in fog generally encountered in the Orly Airport area. The measurement arrangement used consisted of exploring the hot-air stream using temperature probes up to a height of approximately 30 meters (98 ft.) during clear weather conditions. Fog conditions were used to verify results obtained in this fashion. Measurement of the thermal gradient created by the hot-air stream established the approximate dimensions of the fog area cleared under the same wind conditions.

It is the purpose of this report to summarize the experimental procedures and results. Basic information pertinent to the design of an operational installation has been computed. More detailed data taken

*For purposes of clarification, "cleared" volume means total removal of fog; "swept" volume means volume affected by hot air stream in any way.

from the experimental results may prove useful to further improvements in the design. As such, the report will be a useful guide to the documents containing test results and their interpretation. These documents are now in draft form.

2. DESCRIPTION OF INSTALLATIONS

2.1 General. The test station, located to the west of Orly Airport, includes (see Figure 1):

- a rectangular measurement platform used to represent a section of the runway, running east-northeast by south-southwest and surrounded by a service road.
- a row of three jet engines along the southern edge of the platform including the operational prototype in the middle.
- a kerosene supply system fed from two buried reservoirs, each with a capacity of 30 cubic meters (7926 gallons).
- an operations building.

Figure 1. Experimental fog removal station, general view.

2.2 Turbojet engines.

2.2.1 Operational prototype. The operational prototype, or underground blower unit, was designed, constructed and placed in service by Bertin et Cie. A schematic diagram appears in Figure 2.

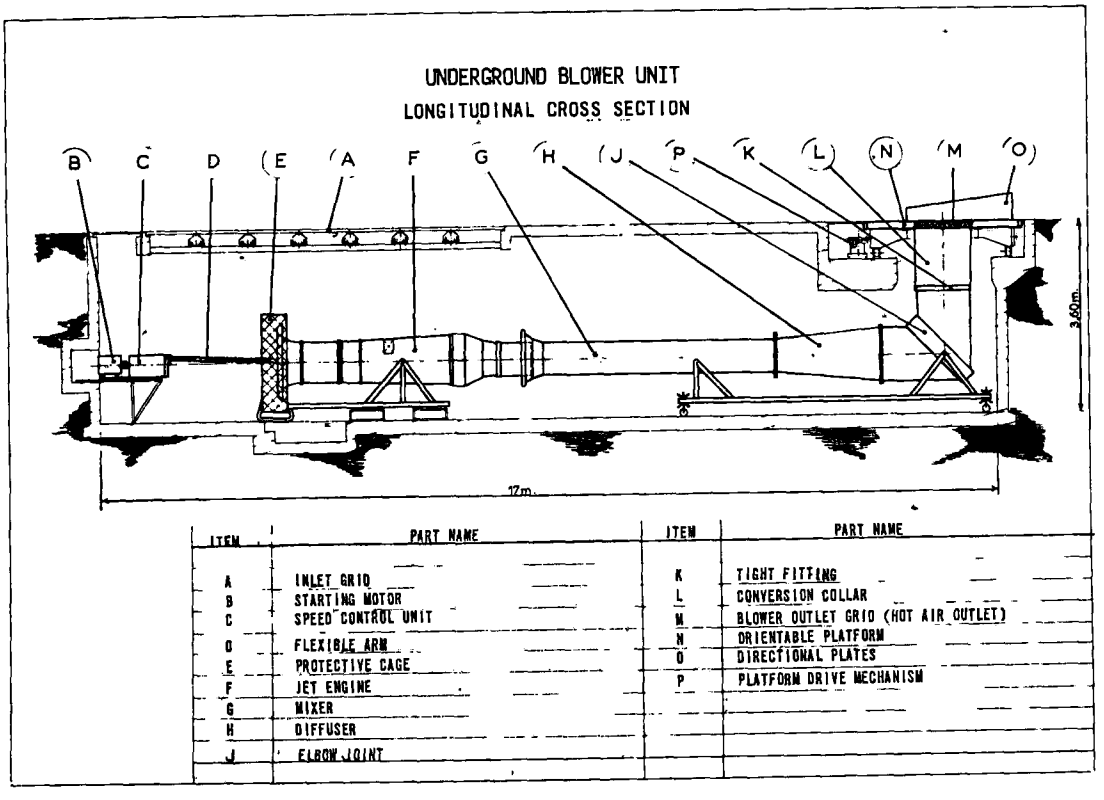


Figure 2. Underground blower unit, schematic drawing.

The engine is placed in a covered trench 17 meters long, 3 meters wide and 3.6 meters deep (56 ft. x 9.8 ft. x 11.8 ft.). The trench roof includes:

. a rectangular intake grid in the front with a trap door.

. a concrete slab in the center.

. a circular platform in the back supporting the outlet grid.

The underground unit is extended by a concrete platform whose purpose is to avoid erosion of the soil from the hot-air stream in the area immediately surrounding the blower outlet grid.

2.2.1.1 Description. The major mechanical componets forming part of the underground blower unit include the following:

a) Jet Engine. This engine is of the ATAR 101 D type. Specifications include:

- idling speed, 3000 rpm
- normal operating speed, 8150 rpm
- inlet air volume, 48 cubic meters per second (1690 cu. ft/sec)
- outlet speed 550 meters per second (1800 ft/sec)
- air temperature, 500°C

This engine rests on a trolley which can assume several longitudinal positions. The inflow channel is fitted with a protective cage. Starting is provided by an electric 10 hp motor coupled with a speed control unit which drives the rotor by means of a flexible arm (see Figure 3). The engine outlet nozzle is fitted with temperature probes.

Figure 3. Inside view of trench seen from front to back.

b) Diluting nozzle. The diluting nozzle includes:

- a mixer
- a diffuser
- a support trolley

During testing required to determine proper operation of the underground blower unit, three mixers were used having respective diameters of:

ψ 760 corresponding to a dilution rate of 1.33
ψ 700 corresponding to a dilution rate of 1.20
ψ 600 corresponding to a dilution rate of 1.05

c) Connecting sleeve. The sleeve connecting the dilution nozzle with the outlet grid consists of:

- a 90° elbow joint equipped with internal vanes and a measurement section at the outflow point.

- a trolley supporting the elbow joint.

- a conversion collar handling flow from the circular section of the elbow fitting to the square section of the grid.

- a tight fitting between the elbow and the conversion collar integral with the orientable platform holding the blower outlet grid.

d) Blower outlet grid. The blower outlet grid includes four components made from heat-resistant steel. Each component, weighing approximately 110 kg (242 lb.), is 150 cm long, 26 cm wide, and 12 cm deep (4.9 ft x 1.8 ft x 0.4 ft). It consists of a square assembly of vanes and crossarms. The 23 vanes have two radii of curvature. The intake plane is vertical, and the outlet angle is 15° from the horizontal. The vanes are designed to cause the hot air to flow in a horizontal direction. The six crossarms are designed to resist torsion.

Hot air is expelled through square openings 4 cm (1.6 in.) on a side. The apparent outlet surface of the grid is 77 dm^2 (1195 $in.^2$). The geometric flow area is approximately 38 dm^2 (589 $in.^2$) and is similar to the outlet cross section of the ATAR engine. The empty/full ratio is 0.58. The initial grid (type A grid) was rectangular and consisted of four elements placed side by side (see Figure 4). The final grid (type B grid) consisted of elements grouped two by two (see Figure 5) with an angle of 21° between them. The outlet grid is set into an orientable platform.

Figure 4 Type A grid.

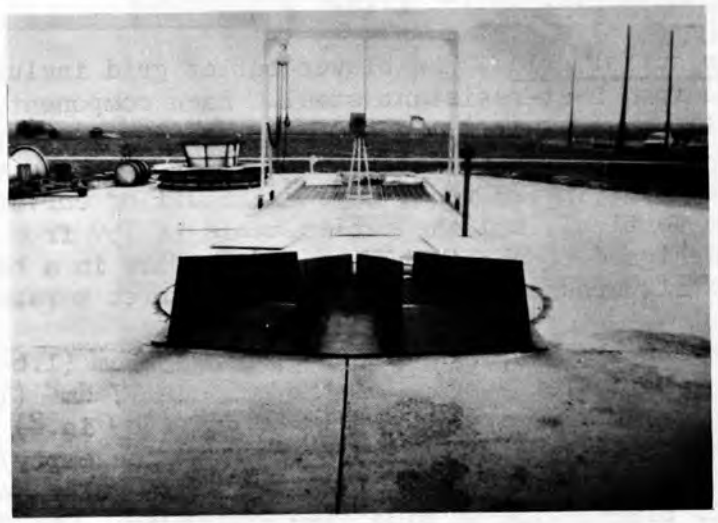


Figure 5 Type B grid.

e) <u>Orientable platform</u>. The orientable platform includes:

- an entirely metallic armature.
- a base which can be disassembled.

- a vertical set of bearings making possible variable orientation of the platform between certain limits and supporting the vertical load.

- a lateral set of bearings supporting lateral loads resulting from lateral expulsion of hot air.

- a set of directional plates located on both sides of the grid to keep the stream of air close to the ground (type B grid includes a twin set of directional plates).

- a unit to control rotation of the platform and its angular position.

2.2.1.2 Operation. Operation of the underground blower unit (engine startup and shutdown, orientation of the blower grid and so forth) is remote controlled from a panel located in the operations building. A weather tight relay unit contains all electrical equipment required for the operation of various units installed in the trench.

2.2.1.3 Location. The blower grid is located 80 meters (262 ft) from the axis of the measurement platform.

2.2.2 Above-ground engines. The two above-ground engines, of the same type as the first, are placed on trolleys and inclined towards the ground at an angle of 4°. They are in line with the underground blower unit. Respective distances from the underground unit are 80 to 100 meters (262 to 328 ft.) for the engine to the west and 90 meters (295 ft.) for the engine to the east. The above-ground engines are designed to provide the underground unit with operating conditions similar to its normal conditions of use when placed in a line including several hot-air generators.

2.3 Experimental methods and means. Since testing was based on the measurement of temperature increases in the volume of air swept by the hot-air streams, equipment capable of measuring these temperature increases had to be installed. The measured results were supplemented by direct observation during fog conditions.

2.3.1 Device to measure air temperatures.

2.3.1.1 Dimensions of air volume to be explored. In the operational version, the maximum height which the cleared air volume will reach is to be approximately 30 meters (98 ft.) on the runway approach. This is the minimum decision point altitude during Category II conditions. Thus, the air temperature measurements were required up to a 30 meter (98 ft.) altitude. From previous testing, it was concluded that the row of engines should be located 70 to 90 meters (230 to 295 ft.) from

the runway centerline. The centerline of the measurement platform used in this test was located 80 meters (262 ft.) from the three jet engines. The width of the platform was established from the fact that most airport runways should fall within a strip 80 meters (262 ft.) wide. Consequently, dimensions adopted for the measurement platform were a length of 250 meters by a width of 80 meters by a height of 30 meters (820 ft. x 262 ft. x 98 ft.). This in turn established the useful volume swept by the three engines at 600,000 cubic meters (21 million cubic feet).

2.3.1.2 Qualities required by the measurement method and choice of means used. The measurement method was to satisfy the following criteria which determined the choice of the means to be used:

- Sensitivity. An accurate measurement should be able to indicate a difference of temperature on the order of 0.5°C.

- Rapidity. Variable winds and the size of the volume to to be examined necessitated a rapid measurement method for correlation with instantaneous wind speed. Thus, the volume had to be explored by continuous movement with reliance on short equipment measurement time constants. In addition, only one continuous recording would be possible for each measuring device.

- Accessibility. Access was required up to a height of 30 meters (98 ft.) above the measurement platform. On the basis of these requirements, a unit was built providing support for temperature sensing devices and recording equipment.

2.3.1.3 Temperature sensing device support system. The previously defined useful volume was measured using a movable vertical grid 30 meters (98 ft.) high by 80 meters (262 ft.) wide supporting the temperature sensing devices and moving on a railroad track installed along the centerline axis of the platform. A 35 meter (115 ft.) tall tower crane was equipped with two horizontal arms, each 30 meters (98 ft.) long. Each arm supported two frames consisting of:

- one upper horizontal crossbeam 32 meters (105 ft.) long raised to a height of 30 meters (98 ft.) above ground level by cables winding around the drum of an electric motor.

- one lower horizontal crossbeam or ballast crossbeam of the same length.

- three steel ropes spaced 16 meters (52 ft.) apart connecting the lower crossbeam with the upper crossbeam.

Thus, in the same plane, the measurement grid consisting of the two frames included six vertical ropes spaced equally along a length of 80 meters (262 ft.) and on which the measuring devices could be hung at various heights. Information collected was transmitted by electric cables located in the lower crossbeam to recording units in the cabin, which forms an integral part of the crane tower.

When not in use, the crossbeams were placed on supports on the ground (see Figure 6). The sensing units were placed in containers protecting them against bad weather conditions. During testing, the crane was generally used with the horizontal arms perpendicular to the crane's axis of translation. The entire assembly moved at a speed of 25 meters (82 ft.) per minute. Thus, the measurement platform could be explored from one end to the other and across its entire width and up to a height of 30 meters (98 ft.) within a span of 10 minutes (see Figure 7).

Figure 6. Measurement platform crane, arms in position, crossbeams on ground.

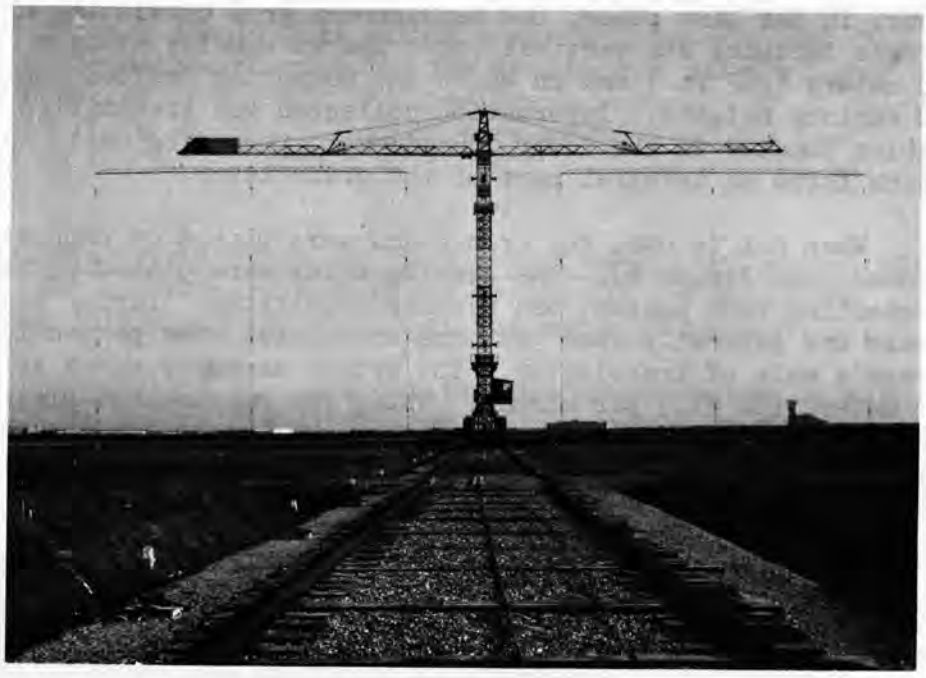


Figure 7. Crane in operation during clear weather

2.3.1.4 Temperature measuring equipment. Once the support problem had been solved, it was necessary to devise a temperature measuring system providing the required qualities, specifically sensitivity and short time constant, while being sufficiently rigid to withstand bad weather and the inevitable shocks either during raising or lowering of the frames or when passing in front of the hot-air streams. This system included:

a) Sensing devices. Thermistors with a time constant of 1 second were used as temperature sensing devices (the time constant is defined by the time required for the increase in temperature indicated by the thermistor placed in a heat source to fall by 63 percent of its value when this heat source is suddenly removed). The response time for these thermistors was thus sufficiently short in order that, taking into account the speed at which the crane was moving, the temperature value indicated at a given time by a sensing device might be correlated with the position occupied at that same instant by the device itself. Each thermistor was placed in an air-cooled tube (see Figure 8) serving two purposes. First of all the tube protected the unit from solar radiation and provided it with mechanical protection. Second of all, it maintained the unit in an air current of virtually constant speed as monitored at the measuring point for the purpose of limiting the influence of gusts of wind on the exchange of heat between the probe and surrounding atmosphere.

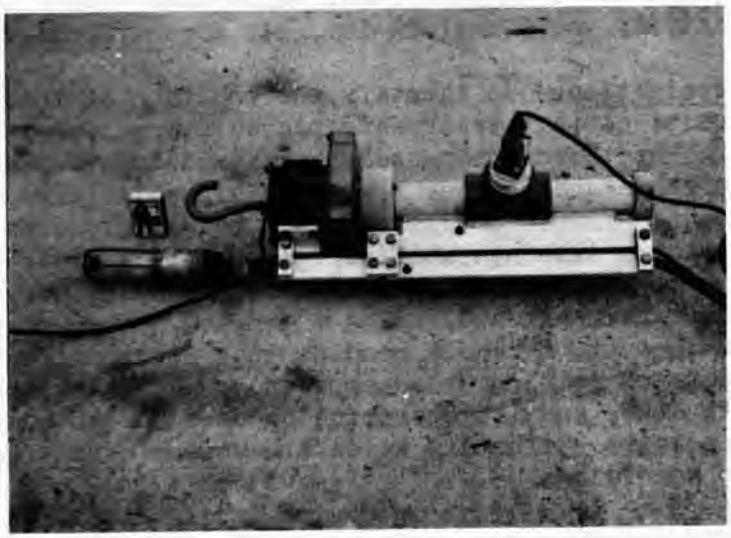


Figure 8. Air-cooled thermistor.

The 24 air-cooled thermistors were placed on the vertical ropes of the measuring grid, four to each rope. The dimensions of the links in the grid, at whose corners were placed the thermistors, were 16 meters (52 ft.) horizontally by 8 meters (26 ft.) vertically (see Figure 7). The six lower thermistors were placed at the 3-meter level (10 ft.). Thus, horizontal cross sectional measurements were made at the 3, 11, 19 and 27m levels (10, 36, 62 and 89 ft.), defining the four values called "reference levels." Each thermistor was previously laboratory calibrated, and it was used in conjunction with a second thermistor, kept in reserve, having the same characteristics. Proper functioning was systematically verified by tests carried out at the start and end of each experimental session.

b) Measurement bridges. To guarantee a sufficient degree of measurement accuracy, each thermistor could be switched to three measurement bridges corresponding respectively to the following temperature ranges: -5°C to +15°C; +5°C to +25°C; and +15°C to +35°C. The operator in the cabin selected one of these ranges at the start of testing as a function of the ambient temperature. When necessary, an indicator made it possible for him to change the range while the volume of hot air was being explored.

c) Recording equipment. Photographic recording equipment was chosen since it offers the advantage of oscilloscope traces of virtually instantaneous response making possible the recording of variations in several parameters, the traces being allowed to overlap and be superimposed. The usable width of recording tape was 8 cm. (3 in.) and recording speed was 40 cm/min (16 in/min). Four

recorders were used. Each was equipped with four to eight measuring tracks, a time base and a manual or automatic time signalling mechanism. Recording sensitivity was 2 mm (.04 in.) per degree Centigrade.

d) Synchronization. To identify the position of the measuring points, a series of contact studs were placed every 10 meters (33 ft.) along the track. As the crane passed by, these studs closed a switch attached to the crane and thus sent a coded signal to the tapes.

2.3.1.5 Conclusion. Although at first glance the methods used might appear to be out of proportion, they made it possible to systematically proceed with the experiment and, using a limited number of personnel, obtain a maximum amount of usable results in a minimum length of time. During the 3 years of testing, the temperature measuring arrangement never once broke down, and its operation soon became an easy routine. The major difficulties, to be discussed elsewhere, consisted in the analysis of the recordings.

2.3.2 Observations during fog conditions. During fog conditions, testing was designed to simultaneously:

- provide temperature measurements
- determine the dimensions of the volume cleared up to the exploration height of the crane.

In the latter instance, direct observation and photography was used.

2.3.2.1 Measurement of the ground pattern of cleared volumes. The ground pattern of cleared volumes was determined by observers. For this purpose, the test zone had been divided up by signs serving as marker points and placed at the corners of squares 10 meters (33 ft.) on a side.

2.3.2.2 Altitude measurement of dimensions of cleared volumes. By day, altitude measurements of the dimensions of cleared volumes were made by using either balloons or, preferably, the frame of the crane and the air-cooled thermistors as reference points. By night, on all four sides and on different levels, the tower of the crane was equipped with narrow-angle spotlights whose beams were aimed horizontally. Three cameras had been installed along the edge of the measurement platform including two on axis at the ends. Image by image these cameras photographed the pattern of the spotlight beams as the crane advanced. Their operation was synchronized with this advance at the rate of one image every 10 meters (33 ft.) covered. A row of beacons, installed on the ground on the measurement platform, was also photographed by one of the cameras. It is worth mentioning that this group of cameras was of little help, most results having been obtained at night with direct observation either using the spotlight beams or light sources of low intensity integral with the air-cooled thermistors. A group of spot-

lights providing some of the ground lighting for the runway had been installed on the measurement platform.

2.3.3 Related equipment. Related equipment included:

2.3.3.1 Wind measuring devices. A high-sensitivity wind sensing device was located near the test station but at sufficient distance not to be influenced by air entering the jet engines. Its recorder, located at the operations stations, operated at a speed of 5 mm (.2 in.) per minute. The recording tape was fed synchronization signals as the crane advanced. A wind sock allowed observers located around the test station to determine the wind direction.

2.3.3.2 Measurement of ambient temperature. The ambient temperature was recorded at the start, during and at the end of each test session.

2.3.3.3 Visibility measurements. A S.A.P.E. transmissometer measuring device had been installed at the test station. It was designed to supply the value of the transmission coefficient of the fog outside the zone affected by the stream from the blower units.

2.3.3.4 Fog quality measurements. During the second phase of testing, the Bertin Company made fog quality measurements including:

- measurement of the liquid water content by aspiration of the cloudy atmosphere through a filter.

- determination of the granulometry of the droplets by means of a continuous flow impact device.

- photographic counting of the droplets.

2.4 Testing timetable. The test station was constructed during the first 6 months of 1965. At the same time, the test procedures were determined along with the method of analyzing the temperature measurement results. Personnel responsible for operating the crane and making measurement observations were trained during the same 6-month period. Construction of the underground blower unit began in March 1965 and was completed in June 1966 On-site experimentation was carried out during two winter sessions in 1966-67 and 1967-68. The crane was disassembled in June 1968.

3. PROGRAM AND SUMMARY LISTS OF TESTS

Final preparations and experimentation with the underground blower unit required many tests taking place during clear weather, most often, and during fog conditions. A test session included a series of operations (measurements, observations and readings) designed to collect characteristic operating data or record performance of the hot air generator. A test session was divided into several sequences, each sequence being characterized by clearly established values of the weather parameters, primarily wind speed and direction, and operating

parameters for the underground blower unit including the types of directional plates, dilution rate, orientation of the blower outlet grid, etc.

3.1 Test classification. Depending on their type, tests were classified into different categories. Each test was identified by a 3-digit number, the first referring to its category and the two subsequent digits indicating its chronological order. A sequence is identified by its order number preceded by the number of the corresponding test. Six categories of tests were defined in this fashion and identified by the series of digits from 2 to 7. They included the following:

- Series 200 tests:
    - tests not directly related to the study of properly so-called fog dispersal.
- Series 300 tests:
    - tests related to final work on underground blower unit.
- Series 400 tests:
    - noise measurement.
- Series 500 tests:
    - experimentation during clear weather conditions.
- Series 600 tests:
    - experimentation during fog conditions
- Series 700 tests:
    - fog seeding operations.

3.2 Series 200 tests.

3.2.1 Definition. Series 200 tests include:

a) Snow and ice tests. It was interesting to determine to what degree a Turboclair installation could possibly be used to remove snow and ice from the runway. For this purpose, two 3 by 3 m (10 x 10 ft.) concrete slabs had been poured flush with the ground at distances of 40 and 70 meters (131 and 230 ft.) from the outlet grid of the underground blower unit.

b) Testing of anti-erosion ground surfaces. It was worth defining the cheapest method capable of combating soil erosion by the air stream from the underground blower unit in the area near the blower platform.

3.2.2 Presentation of results. Results of these tests were recorded in the form of observations and readings on the ground sometimes accompanied by photographs.

3.2.3 List of tests.

a) Snow and ice removal tests:

- test 201 (23 November 1965), light covering of snow and ice on test slab.
- test 202 (14 January 1966), ice on test slab.
- test 204 (4 November 1966), 5 cm (2 in.) of snow.

b) Test planting of anti-erosion grass:

- test 205, planting of cynodon dactylon on 18 July 1968 along the edge of the underground blower slab.

3.3 Series 300 tests.

3.3.1 Definition. Series 300 tests were designed to put the final touches on the underground blower unit. Their purpose was to evaluate the influence of changes in operating characteristics of the hot air generator (dilution rate, directional plates and so forth) on the structure of the air stream and to determine which adjustments would provide optimum performance. The tests primarily consisted of temperature measurements in the absence of the hot air stream.

3.3.2 Test conditions.

a) Measurements. Comparative results were obtained by drawing, for different operating conditions of the underground blower, isothermal curves in a plane perpendicular to the air stream at a distance of 80 meters (262 ft.) from the blower outlet grid. Transversal cross sections were sometimes supplemented by longitudinal cross sections in the air stream's vertical plane of symmetry. Thus, the crane was in a stationary position in the path of the underground blower unit, and its horizontal arms were pointed either parallel to the track for transversal cross sections or normally for longitudinal cross sections. Simultaneous temperature recording lasted on the order of 1 minute for each sequence, the sequences corresponding to different settings of the underground unit. Initial direction of the air stream was perpendicular to the track.

b) Weather conditions. The results of these tests were not to be influenced by weather conditions. Thus, to avoid the influence of the wind capable of severely distorting the air stream at a distance of 80 meters (262 ft.) from the outlet grid, it was necessary that tests only be carried out when wind speed was low, less than 4 m/s (9 mph), and when the wind's direction was close to the orientation of the outlet grid.

3.3.3 Test consistency. These tests reveal the influence of the following parameters:

a) lateral directional plates - geometric form and angle of eight different sets of lateral plates.

b) dilution rates of 1.05, 1.20 and 1.33.

c) engine operating speed, 7,000 to 8,150 rpm.

d) grid form - types A and B

3.3.4 Presentation of results. Values deduced from obtained recorded curves to eliminate variations due either to gusts of wind or the turbulent nature of the air stream were recorded on maps. Isothermal lines were drawn. Thus, the results are presented in the form of maps of isogain temperature curves, transversal and longitudinal cross sections (see figures 9 and 10).

3.3 5 List of tests. The list of series 300 tests appears in Appendix A. It includes 59 sequences, 52 of which were analyzed.

3.4 Series 400 tests.

3.4.1 Definition. Series 400 tests primarily consisted of noise measurement performed by the Paris Airport Laboratory and the Bertin Company. These tests were designed to record the sound level as a whole and by octave ranges at various distances from the underground unit and in various directions (audio spectrum) as well as study the influence on this sound level of changes made in the underground unit.

3.4.2 List of tests. The list of series 400 tests is as follows:

a) Paris Airport:

Test No.	401	10 February 1965
	402	21 May 1965
	403	25-26 May 1965
	432	24 April 1967
	433	22 November 1968
	435	17 January 1969
	436	6 February 1969

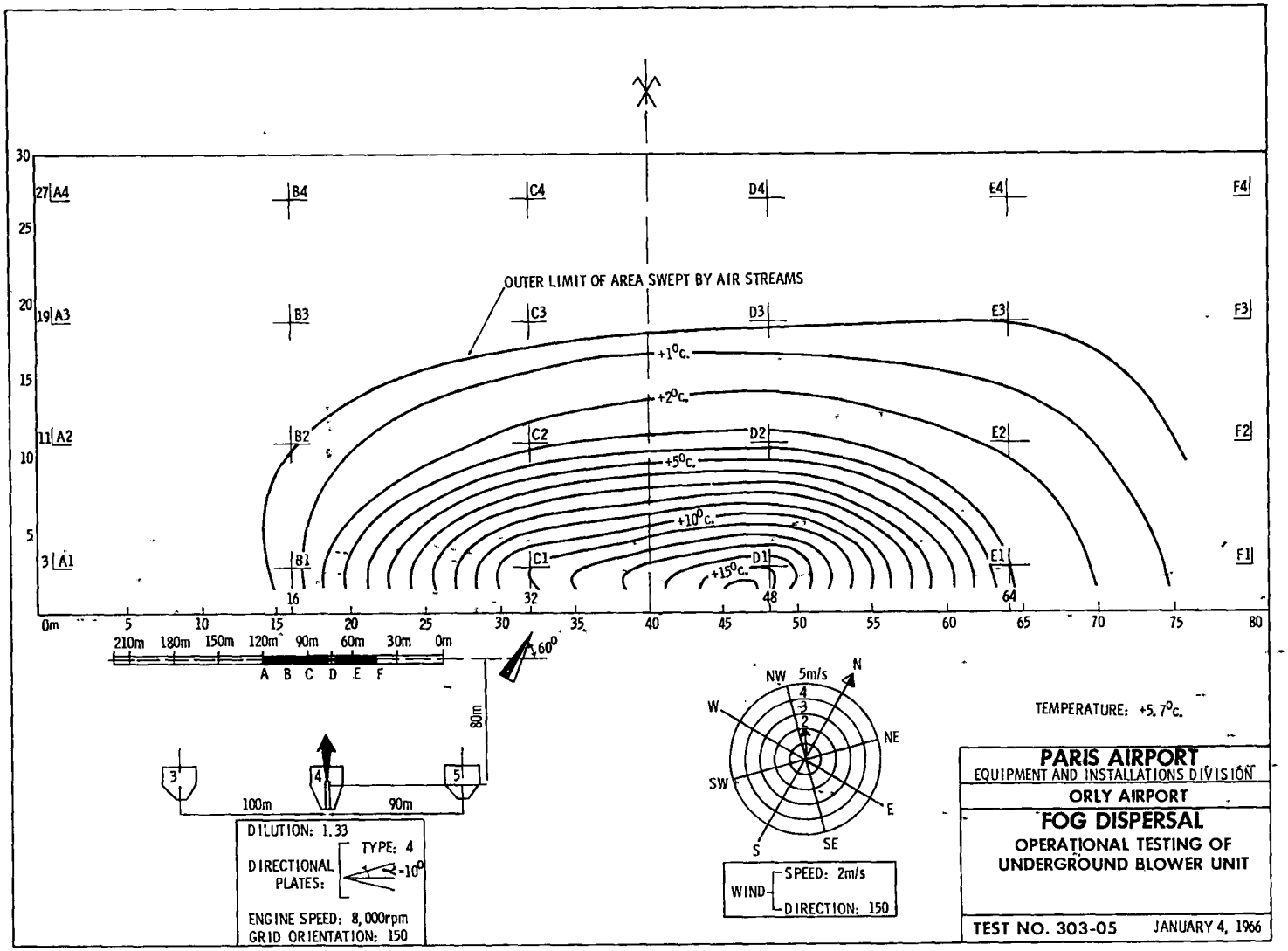


Figure 9. Sequence 303-05, transversal cross section in air stream from underground blower unit at a distance of 80 meters (262 ft.).

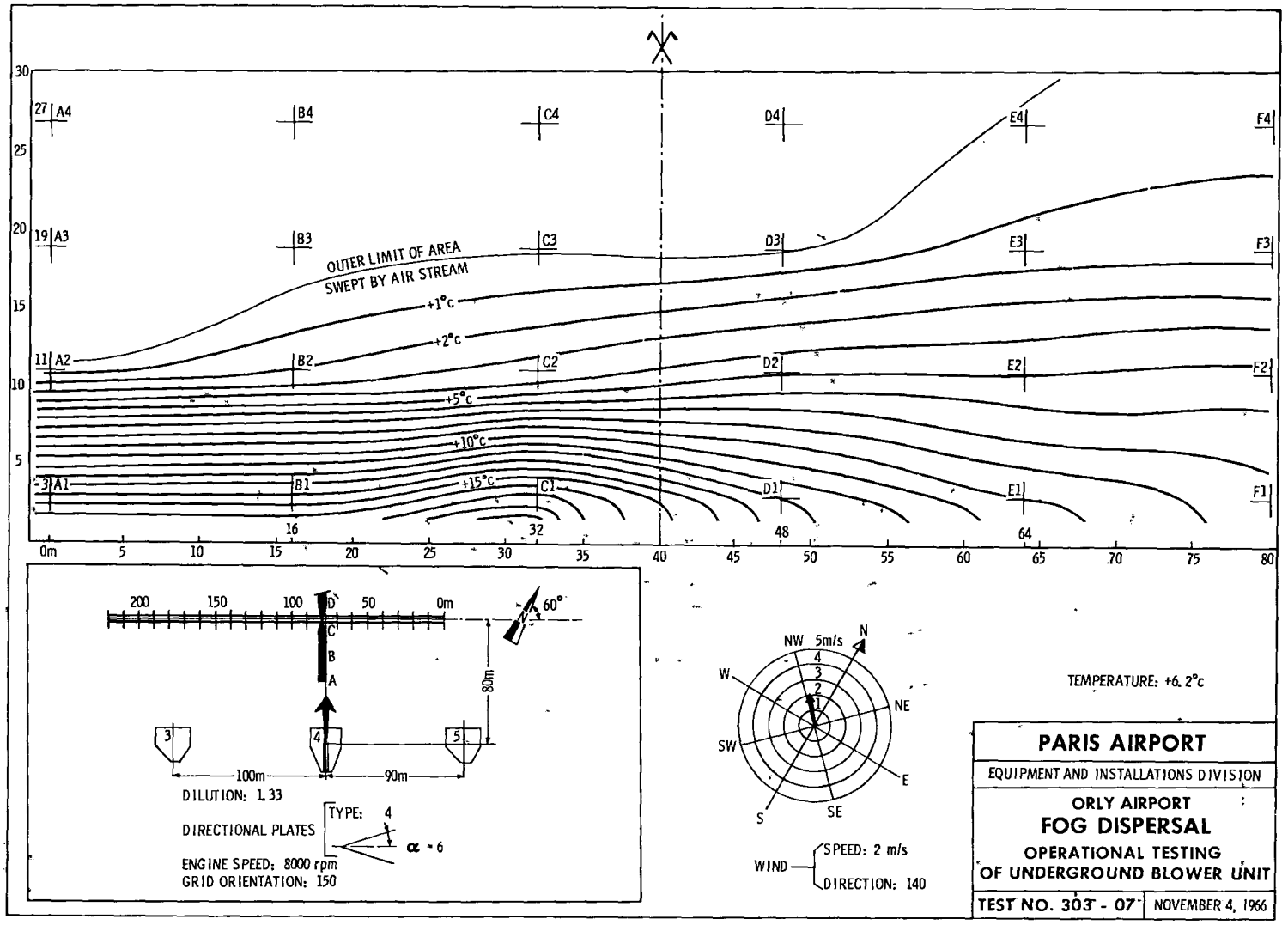


Figure 10. Sequence 303-07, logitudinal cross section in air stream from underground blower unit (+40m to +12m) (131 ft. to 394 ft.).

b) Bertin et Cie.

Test No.	400	8 March 1965
	404	17 June 1966
	405	23 June 1966
	431	24 February 1967
	434	8 January 1969
	437	24 February 1969
	438	27 February 1969
	439	4 March 1969

3.5 Series 500 tests.

3.5.1 Definition. Series 500 tests were designed for the systematic exploration of the measurement platform using temperature sensing devices. The underground blower unit was operated either alone or accompanied by the two above-ground engines.

3.5.2 Designation. The angle between the air stream and the wind is a basic parameter in the Turboclair system, since the configuration of hot air volume is directly influenced by its value. This angle was designated by the letter δ. It is measured positively in the inverse trigonometric direction using the air stream vector as the origin. By analogy with the wind direction, the angle of the air stream direction is measured positively in the inverse trigonometric direction starting with the geographic North. Consequently, since the axis of the measurement platform makes an exact 30° angle with the geographic North, the direction of the air stream along the axis of the trench is at 150°.

3.5.3 Test conditions. A test sequence corresponded to movement of the crane from one end of the track to the other. During this travel time, wind speed and direction had to remain relatively constant. The underground blower unit was operated under optimum conditions as defined by the series 300 tests (in effect, there was interference between the 300 series tests and the first 500 series tests). Thus, a sequence was characterized by wind speed and direction parameters or, more exactly, by the value of the angle δ. Throughout the entire test duration, temperatures measured by the 24 probes were recorded continuously. Tests performed at the start and end of each sequence (recording with and without ventilation by ambient temperature) provided, for each track, the reference basis for temperature increases in the air streams and made it possible to verify equipment functioning.

Series 500 tests were conducted primarily during clear weather conditions and with wind speeds below 6 m/s (13 mph) mostly coming out of an area to the south of the measurement platform. With but a few exceptions justified by favorable wind conditions not previously noted, the ambient temperature was below 20°C; i.e., in the range of temperatures likely to be observed during fog conditions. (The maximum ambient temperature recorded during testing under fog conditions was 19°C on 29 September 1967 (test no. 632)). The major difficulties encountered

during these tests, which constituted the major phase of experimentation, included the following:

- favorable wind conditions, stable out of the south, were relatively uncommon, and this made it necessary to produce a "fog" alert mechanism and procedure capable of being triggered both during the daytime and nighttime.

- several tests had to be postponed once the personnel had been assembled and the crane placed in operation due to changes in the wind.

- several sequences had to be cancelled, the wind not having remained sufficiently stable during movement of the crane.

- the angle of movement of the blower outlet grid was limited by the fact that the air stream of necessity had to be located above the measurement platform.

- the chances of encountering wind conditions making it possible to obtain values for angle δ different from previous angles diminished as the test proceeded.

On the other hand, it is worth emphasizing that the temperature measuring device constructed and operated by SFIM (Societe Francaise d'Instruments de Mesures; French Measurement Company) operated without any problems despite relatively harsh operating conditions.

3.5.4 Presentation of results. Results from a given sequence were presented in the form of isogain temperature curves drawn at the 3, 11, 19, and 27 m (10, 36, 62 and 89 ft.) levels. Each drawing includes the following indications:

- test date and sequence number

- cross section level

- wind speed and direction

- value of angle δ

- ambient temperature

- adjustment of underground blower including orientation of blower outlet grid.

Wind recordings, sychronized with the sequence, are attached to each set of test records. Results of sequence 563-04 were used in Figures 11 and 14.

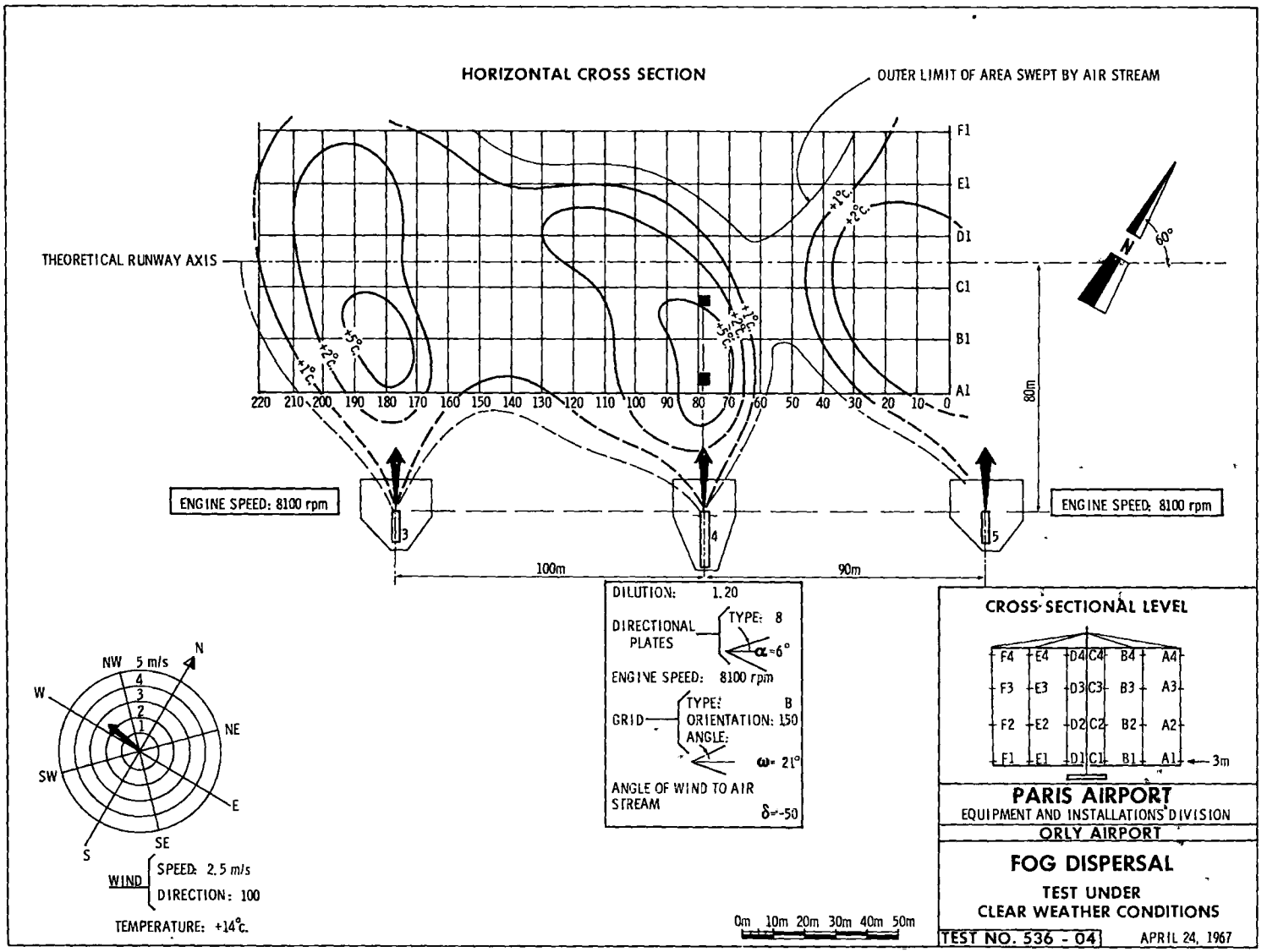


Figure 11. Sequence 536-04 cross sectional drawing at 3 meter (10 ft.) level.

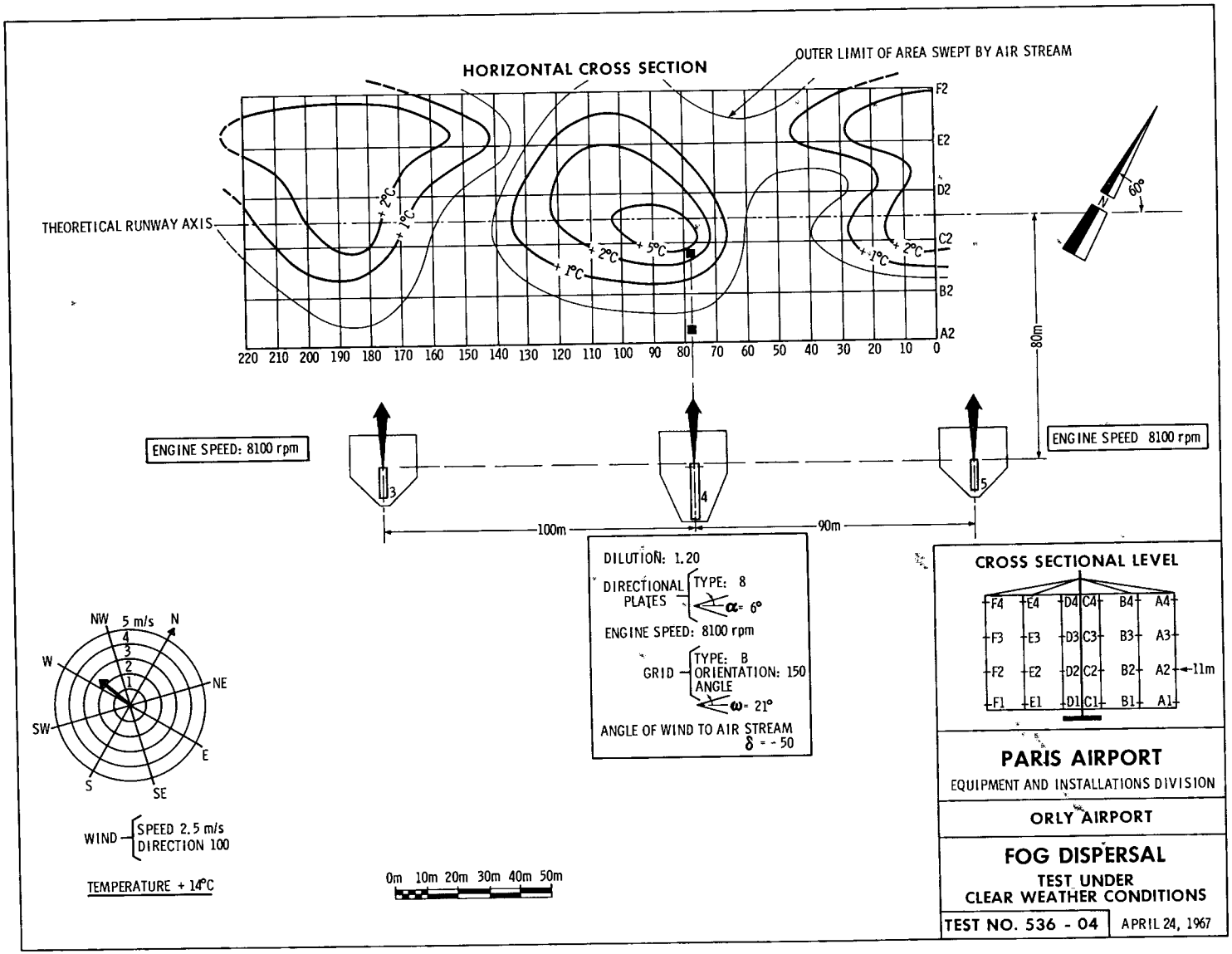


Figure 12. Sequence 536-04 cross sectional drawing at 11 meter (36 ft.) level.

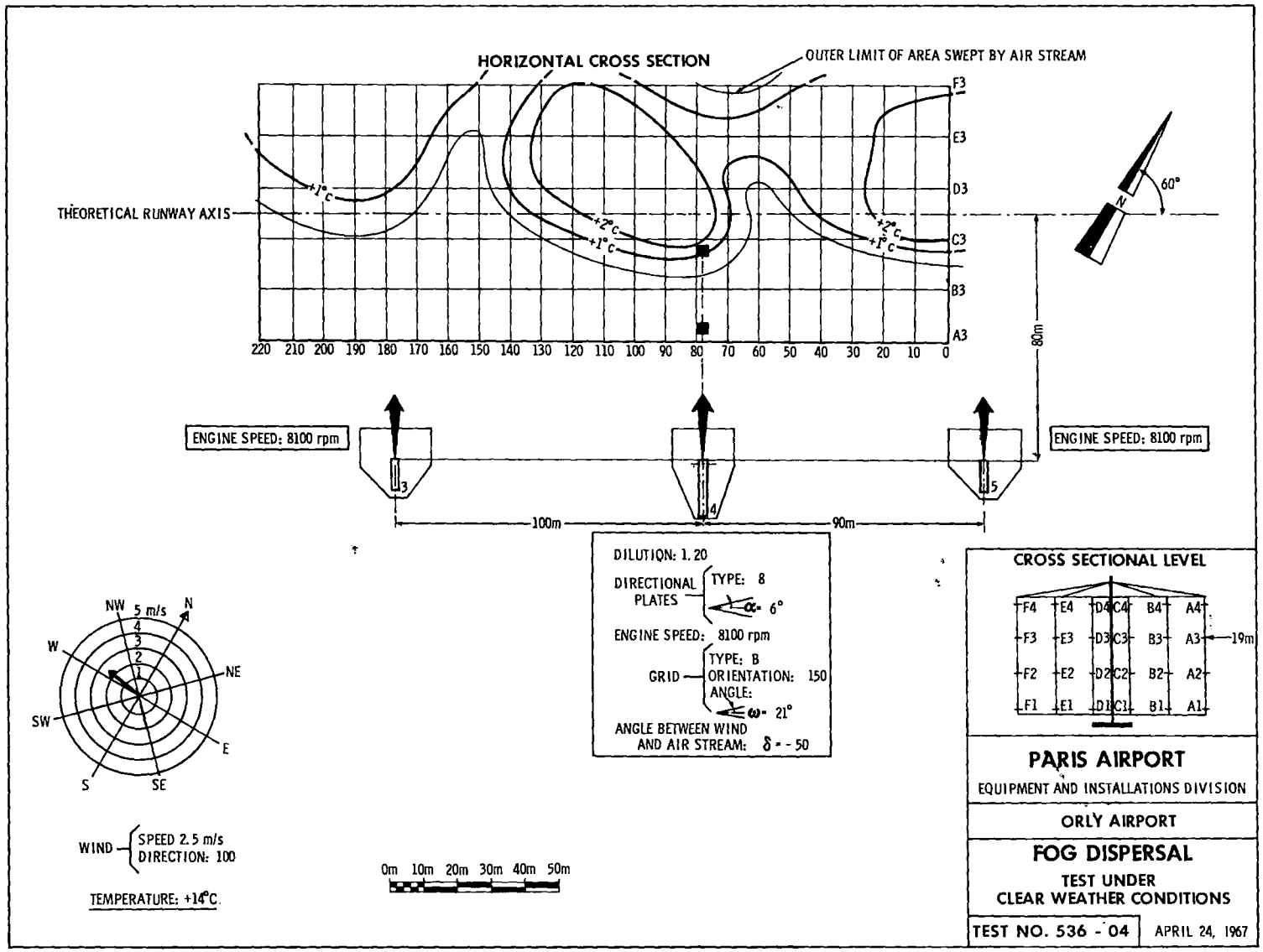


Figure 13. Sequence 536-04 cross sectional drawing at 19 meter (62 ft.) level.

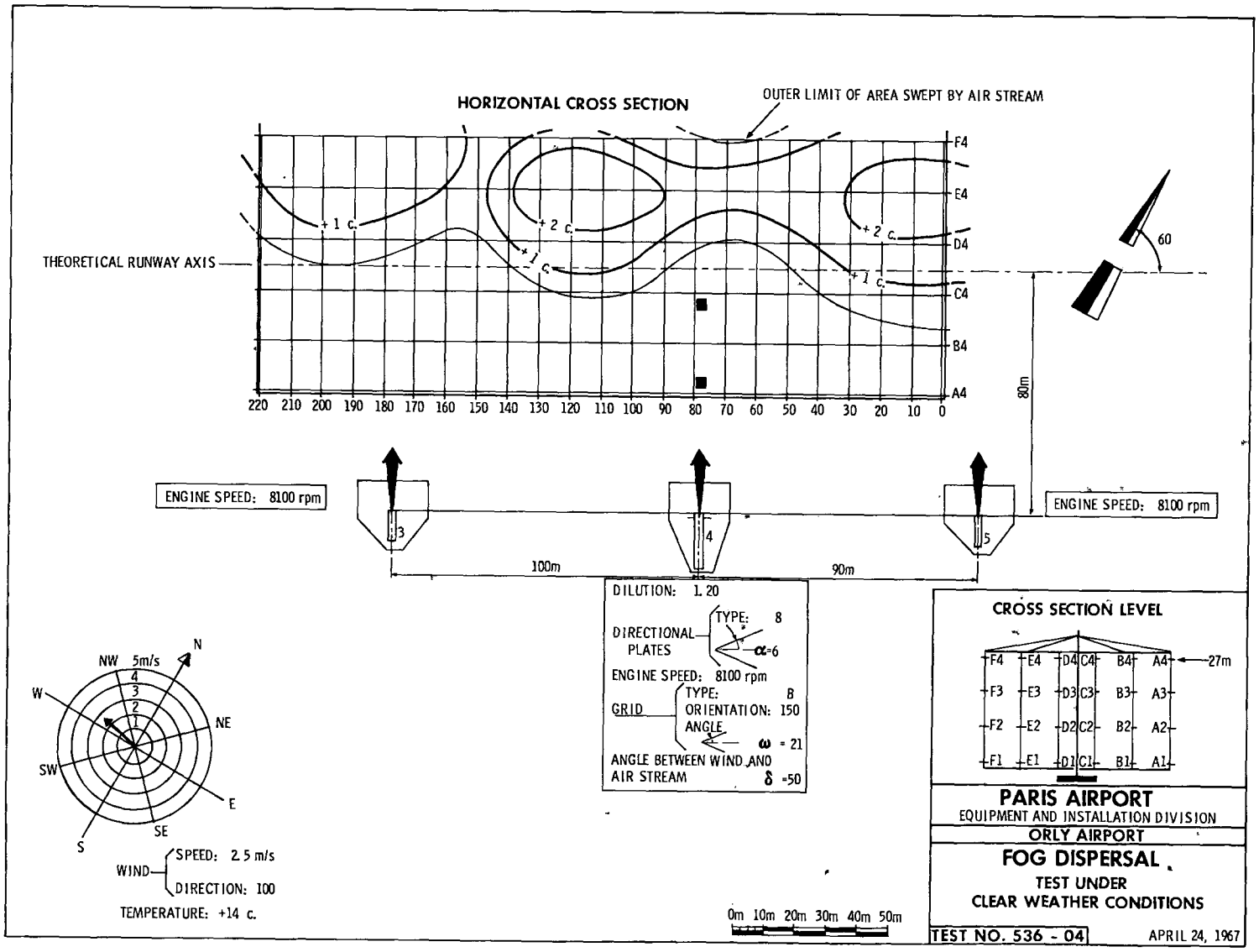


Figure 14. Sequence 536-04 cross sectional drawing at 27 meter (89 ft.) level.

3.5.5 List of tests. The list of series 500 tests appears in Appendix B. It is divided into:

- first series of tests (grid A) from 4 March 1965 to 3 June 1966, 105 sequences of which 58 were not analyzed*, 36 were analyzed and 11 were cancelled.

- second series of tests (grid B) from 24 February 1967 to 7 June 1968, 52 sequences of which 3 were not analyzed and 49 were analyzed.

3.6 Series tests.

3.6.1 Definition. Series 600 tests were classified as tests performed during fog conditions. They consisted of determining the dimensions of the swept volume, these observations sometimes being accompanied by temperature measurements.

3.6.2 Test conditions.

a) Observations. The observations, made as described in Section 2.3, consisted of recording the limits of cleared volumes on the ground and in the air.

b) Temperature measurements. The main objective of testing during fog conditions was to experimentally verify the value of the increase in temperature of the air corresponding to evaporation of the water droplets; i.e., determination of the isogain temperature curve coinciding with the outer limits of the cleared volume. Two methods were used for this purpose including:

- systematic cross sections in the plane of the measurement grid combining temperature observation and measurements in a stationary position (similar to series 300 tests).

- continuous exploration of the measurement platform with "on the fly" recording of the outer limits of the cleared volume and simultaneous temperature recording.

*Since from the very start of testing, no technician was capable of analyzing the data as accurately as was desired, there resulted a certain delay which could not be made up later since priority then was being given to analysis of tests performed with grid B which was used as the final grid.

Figure 15. Crane in operation during fog conditions and zone swept on the ground.

3.6.3 Presentation of results. Observations made on the ground were plotted on maps with, in certain instances, the corresponding temperature isogain curves (see Figure 16). The curves drawn in the vertical planes (see Figure 17) include the corresponding temperature observations and isogain plots.

3.6.4 List of tests. The list of series 600 tests appears in Appendix C. It is divided into:

- first series of tests (grid A) from 15 September 1965 to 26 December 1966, 44 sequences including 1 cancelled and 14 with temperature measurements.

- second series of tests (grid B) from 28 September 1967 to 21 October 1969, 51 sequences including 4 cancelled and 16 with temperature measurements.

Tests 632 to 636 included measurements of fog characteristics.

3.7 Conclusions. In concluding this section, it is worth mentioning a few figures which represent the amount of work included in these tests:

- number of tests, 79.

- number of test sequences, 324.

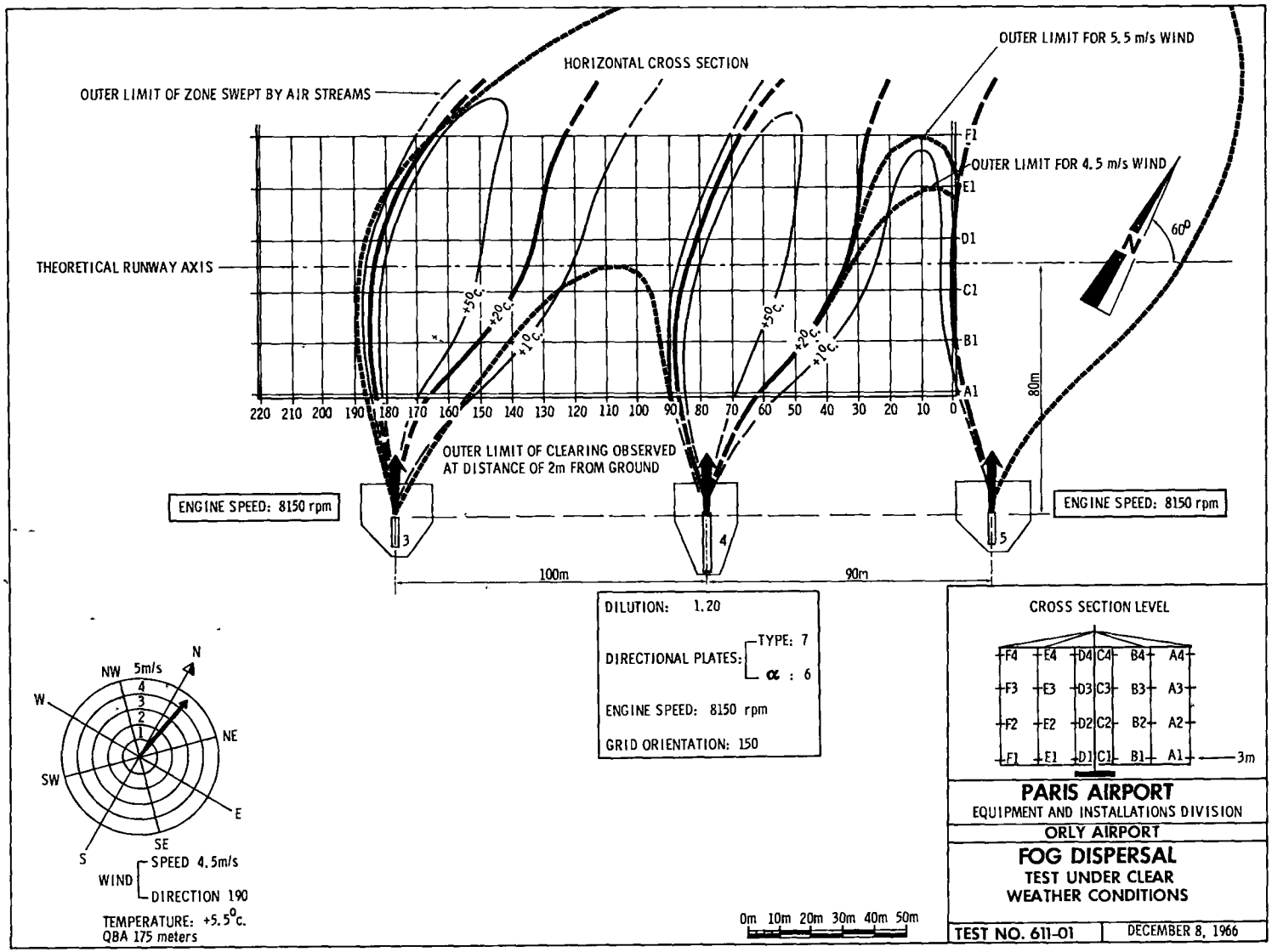
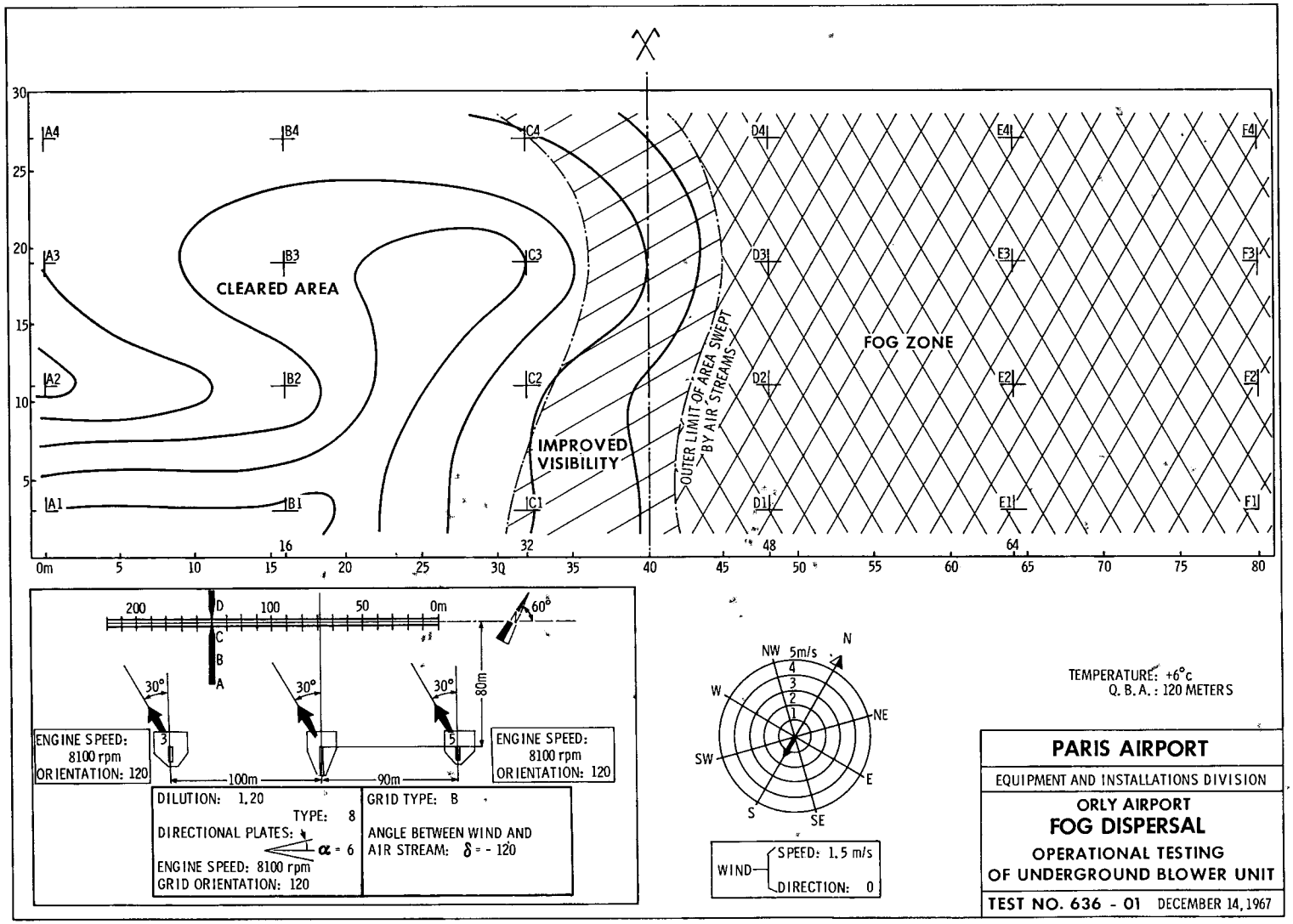


Figure 16. Sequence 611-01, observations at ground level.


CLEARED AREA
IMPROVED VISIBILITY
OUTER LIMIT OF AREA SWEPT BY AIR STREAMS
FOG ZONE
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
ENGINE SPEED: 8100 rpm
ORIENTATION: 120
ENGINE SPEED: 8100 rpm
ORIENTATION: 120
DILUTION: 1.20
TYPE: 8
DIRECTIONAL PLATES:
α = 6
ENGINE SPEED: 8100 rpm
GRID ORIENTATION: 120
GRID TYPE: B
ANGLE BETWEEN WIND AND AIR STREAM: δ = - 120
WIND
SPEED: 1.5 m/s
DIRECTION: 0
TEMPERATURE: +6°c
Q. B. A. : 120 METERS
PARIS AIRPORT
EQUIPMENT AND INSTALLATIONS DIVISION
ORLY AIRPORT
FOG DISPERSAL
OPERATIONAL TESTING
OF UNDERGROUND BLOWER UNIT
TEST NO. 636 - 01 DECEMBER 14, 1967

- duration of tests, approximately 250 hours.

- time required to analyze temperature measurements, approximately 2,500 hours.

Measurements pertaining to the continuous exploration of the volume of hot air alone accounted for:

- 38 km (23.6 mi.) traveled by the crane with simultaneous recording of temperatures

- 2000 meters (6500 ft.) of recorded tape of which 1100 meters (3600 ft.) were analyzed and interpreted.

- 6700 meters (22,000 ft.) of temperature curves analyzed and interpreted.

4. INTERPRETATION OF RESULTS

It is intended that main information be extracted from the experiment and provide basic data indispensable to the design of an operational installation. This data should make it possible to design a facility capable of handling a broad range of clearly defined fog conditions, the best compromise being sought between the range of conditions and the size of the installation. In addition, it will always be possible to rely on test results in dealing with marginal cases and, if necessary, in further extending interpretation in one or many desired directions.

4.1 Final installation testing of underground blower unit. Observations pertaining to the mechanical behavior of the various components of the underground unit, its behavior as a unit, and final installation testing were as follows:

4.1.1 Elastimatic and jet engine starting unit. By 15 November 1969, without any incidents capable of compromising operation of the underground unit, the following had been performed:

- 426 starting operations

- 214 hours 20 minutes of operation

4.1.2 Mechanical assemblies. Difficulties easily corrected on an operational underground unit affected:

- vanes in the connecting sleeve, distortion and cracks.

- mixers, cracks and weld point failures.

- orientable platform - drive mechanism weakness.

4.1.3 Performance of undergound unit. When the underground unit was being designed, including the small scale testing, it was desired to reproduce the characteristics of the air stream of an above-ground jet engine. It can be assumed this goal was reached, since, on one hand, the system of directional plates and grids fitted with inclined vanes imparts good adherence of the air stream to the ground and, on the other, the volume of air swept by the air stream from the buried unit is, generally speaking, similar to the stream from an above-ground engine. These results can easily be checked for all temperature curves recorded by passage of the crane in front of the air streams from the three jet engines. Nonetheless, the orientation angle of the blower outlet grid has a direct influence on the configuration of the air stream. In effect, test sequences nos. 520-01 through 522-05 and 539-02 performed during clear weather when the air streams were respectively deviated by 60°, 75° and 60° to the left (for an observer standing behind the trench and looking at the blower outlet grid) revealed a fall in performance by the underground unit compared with that obtained when the air stream was aimed in a direction closely paralleling the axis of the engine. This decrease in performance was confirmed during tests 639 and 640 which made it possible, under zero wind conditions, to determine the outer limits of the volume swept on the ground as a function of the orientation of the blower outlet grid (see Figure 18).

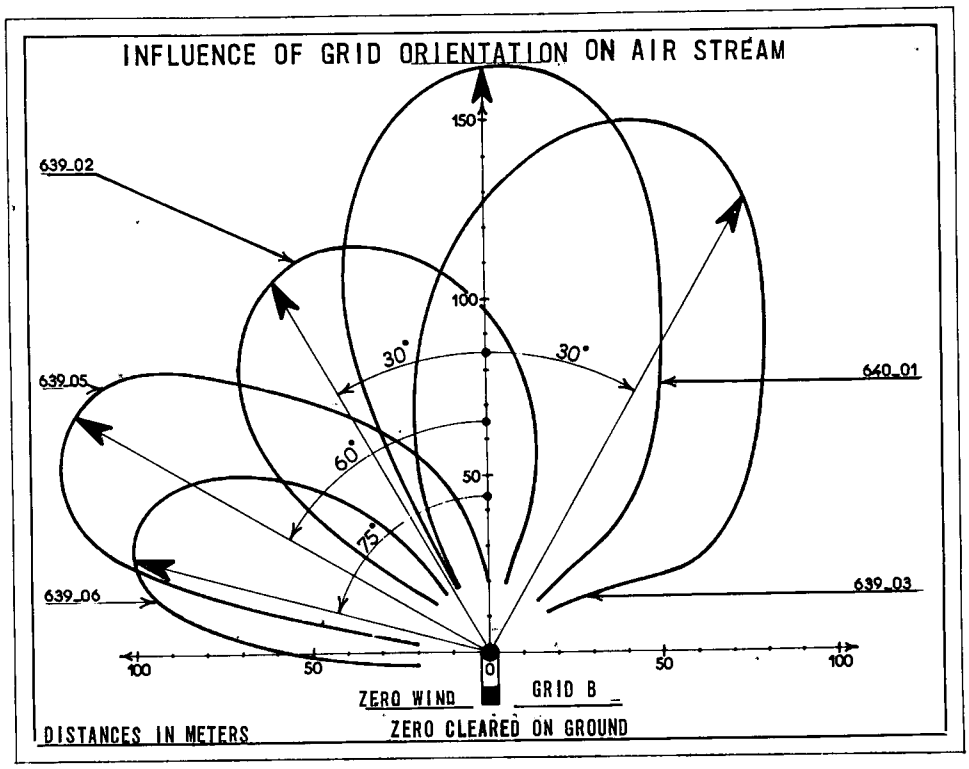


Figure 18. Underground blower unit, grid B - volume cleared as a function of grid orientation.

Comparative study of these different tests indicates that:

- maximum value of the range and width of the air stream on the ground is obtained when the blower outlet grid is pointed along the axis of the engine or in a direction near this axis.

- decrease in the range and width of the air stream is greater when the blower outlet is pointed to the left.

- this phenomenon is not intrinsically related to the grid, since it is also noted in instances when the underground unit is fitted with both grid A and grid B.

- when the blower unit is equipped with grid B, the lobe of the air stream located in the direction of the axis of the engine is larger than the lobe located to the outside, thus indicating that the inner grid element is better supplied with hot air than the outer grid element.

The consequences of these observations are the following:

- as far as possible, the decrease in performance by the underground unit, when the outlet grid is orientated, must be offset by an improvement in the system of vanes in the elbow in the connecting sleeve in order for the air stream to attack the grid at an angle of incidence as close as possible to the vertical.

- In an operational installation, the trenches must be oriented preferably along the bisector of the useful angle of sweep of the orientable platform.

Remark. Most tests accompanied by temperature measurements were performed by pointing the blower outlet grid in a direction close to the axis of the jet engine in order to place the volume of hot air over the measurement platform, and performance of the hot air generator was thus not systematically under estimated.

4.1.4 Erosion of the ground. Adherence of the air stream to the ground directly led to relatively rapid erosion of the ground depending on its consistency. This effect is felt up to a distance of some 40 meters (131 ft.) from the blower outlet grid. This erosion phenomenon was of concern during operational testing of the underground unit.

a) Nature of the phenomenon and consequences. In the immediate vicinity of the blower outlet grid, the surface of the concrete slabs withstood the air stream, although surface cracks were noted resulting from thermal shock produced during rotation of the blower outlet grid with the jet engine in operation. Erosion was heaviest at the point of discontinuity between the slab and the light soil itself. In effect,

there was a cavitation phenomenon which removed the area surrounding the slab. This phenomenon will continue as long as the air stream flows at a relatively high speed. Beyond, the profile of the ground tends to be balanced under the effect of tangential erosion, erosion favored by surface alteration due to atmospheric factors and being more pronounced as vegetation disappears.

There are two types of consequences of these phenomena:

- along the edge of the slab, erosion created an obstacle unacceptable in the area surrounding a runway.

- there is the risk that soil and gravel might be blown on to the runway.

As a remedy, it could be planned to extend the concrete platform to a point from the blower outlet grid where the air stream's speed is sufficiently low, a distance on the order of 30 to 40 meters (98 to 131 ft.) depending on the nature of the terrain. If a platform were built to cover the entire area capable of being swept by the air stream, in other words 180° in certain instances, this would require construction work which would severely increase the cost of the facilities, since concrete slabs and rain water removal systems would be required.

b) Tests and solutions adopted. To reduce the cost of this construction work, it was first decided to design a less expensive type of transition pavement between the concrete platform and the light soil. The blower outlet grid is located in the center of a square platform 20 meters (66 ft.) on the side. Thus, the closest edge of the platform to the grid is approximately 10 meters (33 ft.) the distance at which a speed on the order of 60 m/s (134 mph) and a temperature of 140°C was observed while using grid A. As soon as the underground blower unit was placed in service, it created a depression along the edge of the slab reaching some 20 cm (7.8 in.) in depth, and natural vegetation was destroyed up to some 40 meters (131 ft.) from the blower outlet grid.

To remedy erosion along the edge of the platform, the platform was extended in three directions using a notched pattern consisting of triangular concrete slabs of base 5 m (16 ft.) and height 8 m (26 ft.). This arrangement decreased the rate of erosion but was not sufficiently effective. In the front of the platform, intervals between the notches were then filled in with various types of asphalt pavement. The asphalt rapidly disintegrated under the combined effect of the speed and temperature of the air stream. The switch from grid A to grid B considerably reduced the extent of ground erosion. Lastly, in 1968 it was decided to plant a hardy strain of couch grass, cynodon dactylon. Testing demonstrated that at a distance of 15 meters (49 ft.) from the blower outlet grid, this strain of grass is capable of withstanding the speed and temperature of the air stream. Even when burned on the surface,

its roots remain intact, and it rapidly regenerates. This accounts for its ability to hold soil in place.

Thus, in an operational version it is suggested to construct a platform of concrete slabs 15 to 20 meters (49 to 66 ft.) in radius extended to a distance of 40 meters (131 ft.) by planting of cynodon dactylon in the sector corresponding to the wedge of land over which the air stream flows.

4.1.5 Conclusion. The operational installation must be highly reliable since:

- access will be relatively difficult to underground units placed along the runway when service and repair is required.

- any failure of a jet engine to start or any unplanned halts in operation will lead to formation of fog across the runway whose effect on pilot visibility conditions is difficult to predict.

One of the main results of the test procedures was demonstation of the reliability of the hot air generator. In effect, the total duration of its operation constituted an endurance test representing more than 5 years of normal use without a major failure in an operational version at an airport in the Paris area.

4.2 Experimental testing of underground blower unit. Experimental testing of the underground blower unit was performed during the series 300 tests consisting of temperature measurements in longitudinal and transversal planes in the air stream. A first series of tests, including 56 sequences (301-01 to 307-08), led to changes in the initial blower outlet grid. A second series of tests, including 3 sequences, verified the characteristics of the new grid.

4.2.1 Study of results of first test series (grid A). The transversal cross sections (T) performed at a distance of 80 meters (262 ft.) from the blower unit were compared while taking into account the height reached by the air stream, its width and the maximum temperature evaluation recorded in the center. In the case of two families of similar curves, the results of the longitudinal (L) cross sections and wind characteristics (speed and direction) were taken into account. Major results were as follows:

(a) Influence of angle of opening of directional plates (angle 2 α).

a-1) Case: engine speed 8,000 rpm; dilution 1.33.

- Type 1 directional plates

Comparison
$\alpha = 6^{\circ}$ (sequence 303-01)
$\alpha = 10^{\circ}$ (sequence 303-02)
$\alpha = 14^{\circ}$ (sequence 303-03)

Results - Case $\alpha = 6^o$ and $\alpha = 10^o$, identical
Study of longitudinal cross sections
Choice: $\alpha = 6^o$

- Type 4 directional plates

Comparison
$\alpha = 6^o$ (sequence 303-06)
$\alpha = 10^o$ (sequence 303-05)
$\alpha - 14^o$ (sequence 303-04)

Results - Choice: $\alpha = 6^o$

- Type 5 directional plates

Comparison
$\alpha = 0^o$ (sequence 304-07)
$\alpha = 6^o$ (sequence 304-06)
$\alpha = 14^o$ (sequence 304-05)

Results - Case $\alpha = 0^o$ and $\alpha = 6^o$ identical
Study of longitudinal cross sections
Choice: $\alpha = 0^o$

- Type 6 directional plates

Comparison
$\alpha = 6^o$ (sequence 301-02)
$\alpha = 8^o$ (sequence 301-03)
$\alpha = 10^o$ (sequence 301-04)
$\alpha = 12^o$ (sequence 301-05)
$\alpha = 14^o$ (sequence 301-06)

Results - Choice: $\alpha = 6^o$

- Type 7 directional plates

Comparison
$\alpha = 6^o$ (sequence 302-06)
$\alpha = 10^o$ (sequence 302-05)
$\alpha = 14^o$ (sequence 302-04)

Results - Choice: $\alpha = 6^o$

a-2) Case: engine speed 8,000 rpm; dilution 1.20.

- Type 4 directional plates

Comparison
$\alpha = 0^o$ (sequence 307-01)
$\alpha = 6^o$ (sequence 307-03)

Results - Choice: $\alpha = 0^o$

- Type 5 directional plates

Comparison	$\alpha = 0^{\circ}$	(sequence 306-07)
	$\alpha = 6^{\circ}$	(sequence 306-01 and 05)
	$\alpha = 12^{\circ}$	(sequence 306-02 and 03)

Results - Choice: $\alpha = 6^{\circ}$

Conclusion - The angle of the directional plates does not seem to have a major influence on the characteristics of the air stream. Nonetheless, it can be said there is a tendency towards an improvement in the air stream when the angle of opening is diminished. Thus, a minimum value will be chosen for this angle; i.e., with the directional plates parallel to the edge of the blower outlet grid.

(b) Influence of type of directional plates.

Engine speed 8,000 r.p.m.
Dilution 1.33

The following were compared:

- Type 1 directional plates

height 20 cm (7.8 in.)
length 2 m (6.5 ft.), (sequence 303-01)

angle of opening, $\alpha = 6^{\circ}$

- Type 4 directional plates

height 50 cm (19.6 in.)
length 2.50 m (1.2 ft.), (sequence 303-06)

angle of opening, $\alpha = 6^{\circ}$

- Type 5 directional plates

height 60 cm (23.5 in.)
length 2.50 m (8.2 ft.), (sequence 304-07)

angle of opening, $\alpha = 0^{\circ}$

- Type 6 directional plates

height 60 cm (23.5 in.)
length 1.30 m (4.3 ft.) plus one divergent element 1.20 m (4 ft.) forming an angle of 6° with the preceding (sequence 301-02)

angle of opening, $\alpha = 6^{\circ}$

- Type 7 directional plates - type 6 directional plates plus small internal directional plates

height	55 cm	(21.5 in.)	
length	1 m	(3.3 ft.)	(sequence 302-06)

angle of opening, $\alpha = 6^{\circ}$

- Results Choice: type 7 directional plates

Remark - It should be noted that types 2 and 3 directional plates were eliminated from the outset as unsatisfactory, and as such no further systematic tests were devoted to them.

(c) Influence of engine speed.

Dilution rate, 1.20

- Type 4 directional plates, $\alpha = 0^{\circ}$
  Comparison - 8000 rpm (sequence 302-01)
  8150 rpm (sequence 307-02)

  Results Choice: 8150 rpm

- Type 4 directional plates, $\alpha = 6^{\circ}$
  Comparison - 8000 rpm (sequence 307-03)
  8150 rpm (sequence 307-04)

  Results Choice: 8000 rpm

- Type 5 directional plates, $\alpha = 0^{\circ}$
  Comparison - 8000 rpm (sequence 306-07)
  8150 rpm (sequence 306-08)

  Results - identical

- Type 5 directional plates, $\alpha = 6^{\circ}$
  Comparison - 8000 rpm (sequence 306-05)
  8150 rpm (sequence 306-06)

  Results - identical

- Type 5 directional plates, $\alpha = 12^{\circ}$
  Comparison - 8000 rpm (sequence 306-03)
  8150 rpm (sequence 306-04)

  Results - identical

Conclusion - The increase in engine speed from 8000 to 8150 rpm has no effect on cross sections analyzed at 80 meters (262 ft.) from the underground blower unit. An operating speed of 8150 rpm was used corresponding to a longer air stream range.

(d) Influence of dilution.

Engine speed - 8000 rpm

Two nozzles were studied with respective dilution rates of 1.20 and 1.33. The third nozzle, with a dilution rate of 1.05, turned out to be useless due to distortion resulting from heating effects encountered during operation.

- Type 4 directional plates, $\alpha = 6^{\circ}$
  Comparison - dilution, 1.33 (sequence 303-06)
  - dilution, 1.20 (sequence 307-03)
  Results - identical
- Type 5 directional plates, $\alpha = 6^{\circ}$
  Comparison - dilution, 1.33 (sequence 304-06)
  dilution, 1.20 (sequence 306-05)
  Results Choice: 1.20
- Type 5 directional plates, $\alpha = 0^{\circ}$
  Comparison - dilution, 1.33 (sequence 304-07)
  dilution, 1.20 (sequence 306-07)
  Results Choice: 1.20
- Type 5 directional plates, $\alpha = 14^{\circ}$ and 12°
  Comparison - dilution, 1.33 (sequence 304-05)
  dilution, 1.20 (sequence 306-03)
  Results Choice: 1.20

Conclusion - The dilution rate adopted was 1.20

(e) Conclusion: Operating parameters for grid A - These results indicate that variations within the limits explored for various operating parameters for the underground blower unit do not require extensive changes in the characteristics of the air stream. The optimum values used for grid A were as follows:

- engine operating speed, 8150 rpm
- dilution rate, 1.20
- directional plates, type 7, $\alpha = 6^{\circ}$

This first series of tests indicated that distribution of the hot air depended essentially on the shape of the blower grid which remained unchanged during the tests.

4.2.2 Changes in the blower grid.

a) Definition of the new grid. - Transversal cross sections indicate that the width of the air stream obtained with grid A, whose

limits were set by the +2°C temperature isogain, is on the order of 50 to 60 meters (164 to 197 ft.) at a distance of 80 meters (262 ft.) from the blower grid. Furthermore, in the center of the air stream is a concentrated high-speed nucleus with a temperature on the order of 15 to 20°C above the ambient temperature. We thus determined the possibility of broadening the air stream while decreasing the concentration of axial energy in order to make the following improvements in the underground blower unit mentioned in increasing order of importance:

- decrease in ground erosion
- probability of wider spacing between engines in an operational installation
- better distribution of calory input to the volume to be cleared
- decrease in the amount of turbulence above the runway

At the close of the 1965-66 experimental series, the Bertin Company was requested to use existing components to build a twin grid consisting of two rectangular blower channels forming between them an angle yet to be defined (see Figure 5).

b) Scale model study of new grid.- The scale model study of the new blower grid was assigned to the Bertin Company and completed during the second half of 1966. Tests performed on a modified one-tenth scale of the grid (see Figure 19) previously used for design of the underground blower unit were the subject of a detailed report (Bertin et Cie, "Report on Tests Performed on One-Tenth Scale Model," Technical Bulletin No. 25-234, 1 February 1967).

Figure 19. One-tenth scale model of Type A Blower outlet grid

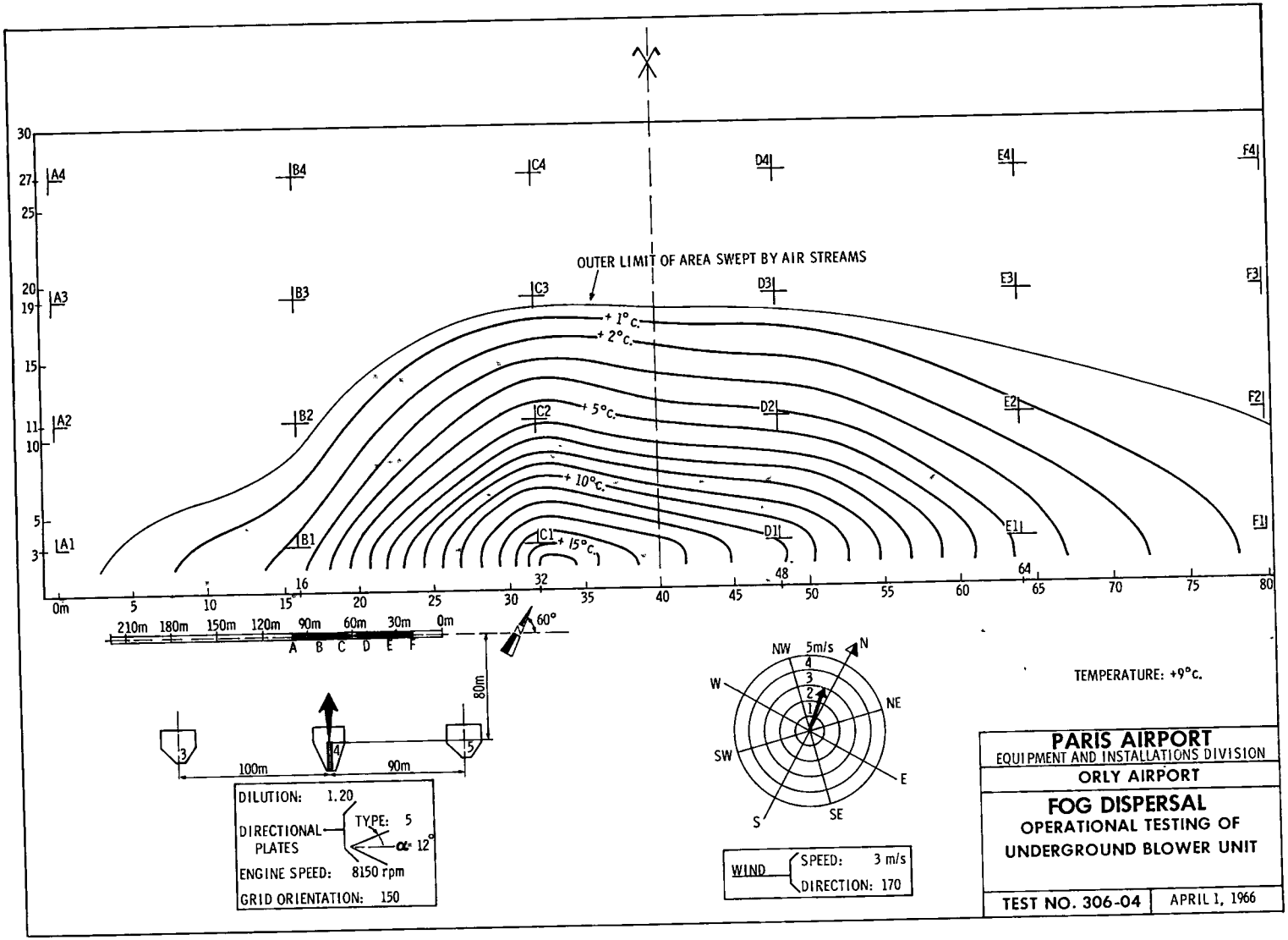


Figure 20. Grid A - Transversal cross section (sequence 306-04).

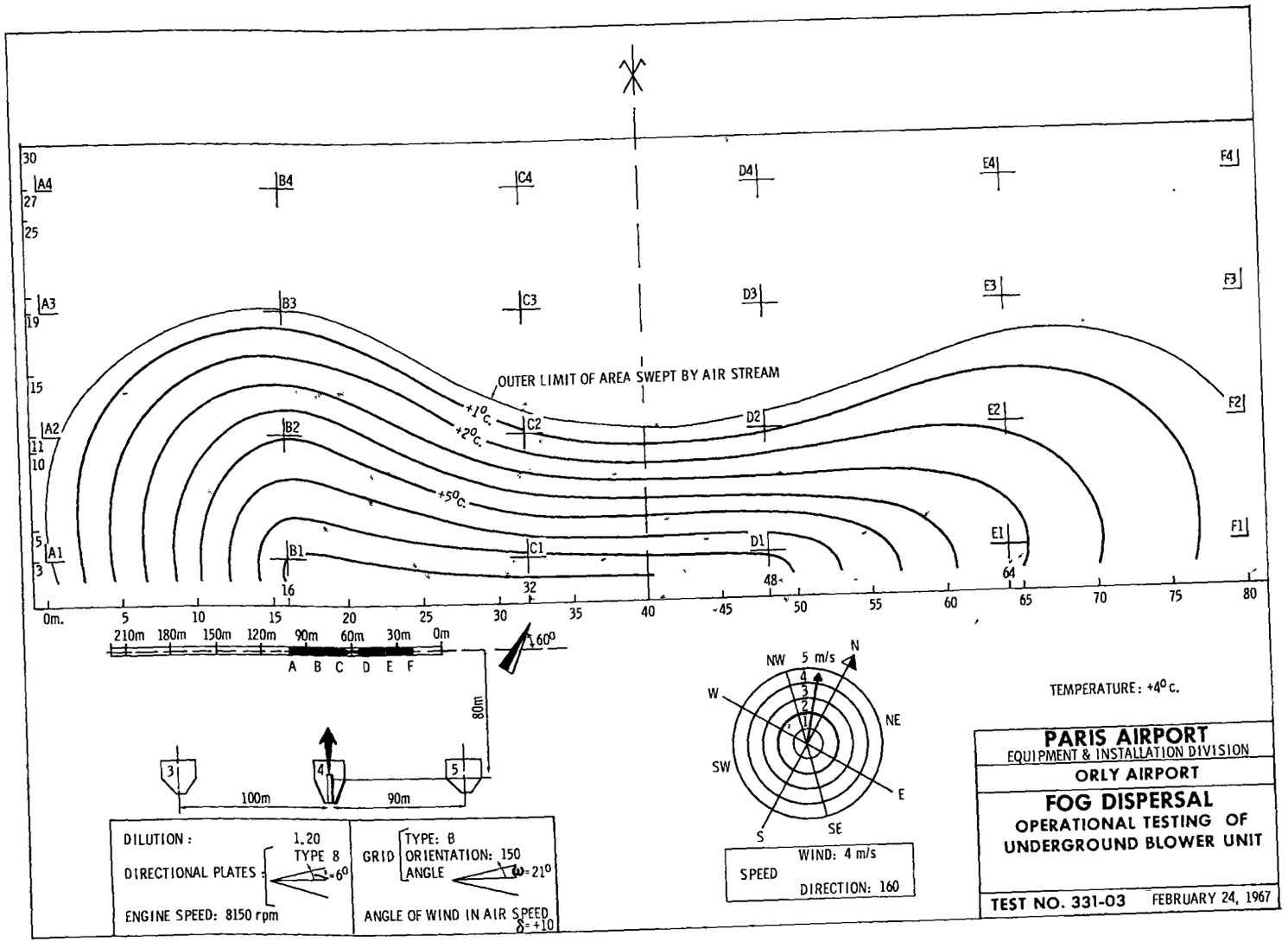


Figure 21. Grid B - Transversal cross section (sequence 331-03).

The report concluded that dividing the grid into two parts made it possible to obtain:

- a 35 percent increase in the size of the air stream
- a decrease in turbulence
- better distribution of speed and thus of kinetic energy
- 40 percent decrease in on-axis speed

On the basis of the results, the 24° angle (between grid elements) gives the best results but is an outer limit which must not be exceeded if an acceptable value of speed is to be maintained. In conclusion, it was suggested that a new full-scale grid should be designed providing an angle of either 21° or 24°.

4.2.3 Construction and testing of the new grid. The underground blower unit was equipped with the new blower outlet grid, or grid B, in January 1967. Its adaptation required the replacement of several components including the conversion collar and the orientable platform. Transversal cross sections appearing below (see Figures 20 and 21) indicate the influence of the change on the air stream in agreement with small-scale test results, specifically better broadening of the air stream and widening of the central nucleus with a considerable decrease in its temperature.

4.2.4 Conclusion. Series 300 tests indicated there were but a few means of changing the shape of the air stream through adjusting the various assemblies making up the underground blower unit. The key component is still the blower outlet grid on which advanced work was carried out. Since turbulence which might possibly develop constitutes a stumbling block for the Turboclair method, we prefer to reduce it as much as possible to the detriment of the air stream's resistance to the wind, to a certain degree, to its range, factors which were moreover introduced into the systematic study of the volume filled by the hot air.

4.3 Noise measurements. To eliminate, as much as possible, the influence of wind and ground effects in order to obtain coherent, significant values as a reference base for the measurement of noise produced by the underground blower unit, a circle with a 100 meter (328 ft.) radius around the blower was used. Major results were as follows:

4.3.1 Comparison of an above-ground engine with the underground blower unit (test 405). A sizeable gain was obtained by using the underground blower unit fitted with the type A blower outlet grid in comparison with an above-ground engine. This was on the order of 5 to 10 PNdb on the side where the combustion gases are expelled and 1 to 6 or 8 PNdb on the air intake side. Low frequency levels were higher on the air intake side for the undergound blower unit in comparison with the above-ground unit. Attenuation becomes considerable on the side of the air stream

starting with the fourth octave (300 to 600 Hz), between 10 and 15 db, and above, depending on the direction.

4.3.2 Comparison of the noise level of the underground blower unit fitted with grid A and the underground unit fitted with grid B and a makeshift sound reducing device (tests 405 and 432). The sound reducing device consisted of absorbent panels placed horizontally in a baffle arrangement under the intake grid. Improvements obtained with grid B and the sound absorbent material vary from 1 to 10 PNdb depending on the direction. Attenuation is maximum in those directions near the air stream where it has a greater effect on the low frequencies (influence of the grid). In addition, the upper frequencies are attenuated especially on the intake side (influence of sound absorbent material).

4.3.3 Acoustical characteristics of undergroud blower unit. Table 1 indicates sound levels for the underground unit by octave range in a circle with a radius of 100 m (328 ft.) (grid B and makeshift sound absorbent installation on intake side). The total noise level is represented in Figure 22 below.

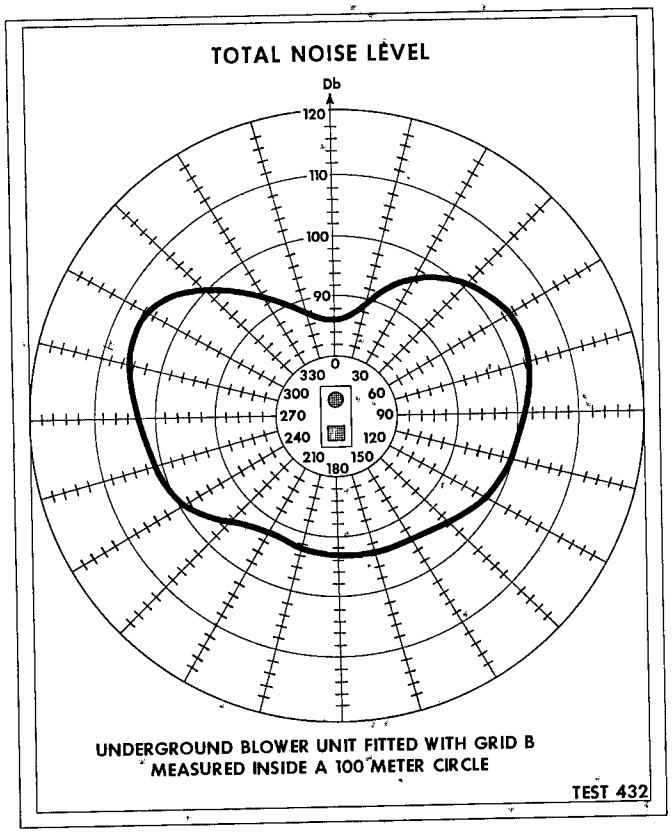


Figure 22. Underground blower unit, total noise level at distance of 100 m (328 ft.) (engine speed, 8,150 rpm).

TABLE 1. UNDERGROUND BLOWER UNIT - NOISE MEASUREMENT RESULTS - TEST 432

Measuring points	Total	Level in Octave Range No. (db)								PNdb
		1	2	3	4	5	6	7	8	
Engine axis, exhaust point 0°	86	85	72	67	58	56	54	52	50	81
30°	96	94	89	79	70	65	63	58	53	93
60°	103	98	99	93	84	70	65	61	60	101
90°	101	94	96	96	88	72	64	60	60	101
120°	98	91	93	93	80	67	65	60	60	98
150°	94	87	89	87	80	68	66	63	58	95
Air intake 180°	93	87	89	84	81	74	75	73	64	97
210°	92	95	87	84	79	70	68	63	54	93
240°	99	90	93	95	87	74	72	66	62	101
270°	102	94	98	97	91	74	72	70	65	104
300°	105	95	101	98	88	77	73	71	65	105
330°	93	91	90	78	66	62	62	60	52	92

It is worth noting that, for an above-ground engine, the maximum noise directions appear at an angle of 45° on each side of the air stream, whereas here they are offset to an angle of 70°. This will be important in evaluating the noise level generated by an operational facility in a given direction while taking into account the most likely orientation of the outlet grids.

4.4 Test during fog conditions. The main objective of testing under fog conditions was to crosscheck temperature measurements. Thus, in the following paragraph appears a description of the analysis of temperature recordings related to exploration of the measurement platform.

4.4.1 Analysis of temperature measurements. Analysis of the temperature measurements constituted the main difficulty in the testing, since it necessarily introduced a factor of personal evaluation. Nonetheless, variability in this factor was limited, as much as possible, by the fact that the work was performed by the same technician, who used as much care as possible and produced the desired degree of accuracy. The analytic procedure consisted of the following:

a) rapid verification of the recorded tapes by noting any possible failure in the measurement or synchronization system, a failure capable of cancelling the corresponding sequences. Any operating failure was made known to measurement personnel in order that repairs could be made immediately.

b) identification of the sequences and synchronization signals by referring to test records of the command station and measurement operator.

c) identification of each recording of the various probes and recording of the operating ranges. This identification required a very high degree of accuracy. In effect, on each tape, up to eight temperature values were being recorded simultaneously, the corresponding curves being allowed to either coincide or overlap (see Figure 23). Identification of the curves was facilitated by: electric zero reset lasting less than one second and systematic at the start and end of each sequence and periodical, in a given order, in the interval; the deviation direction of the trace and the temperature elevation, upwards for certain channels and downwards for the others; the selection on the same tape of channels affected differently by the air stream as a function of the position of their probes in the measurement grid.

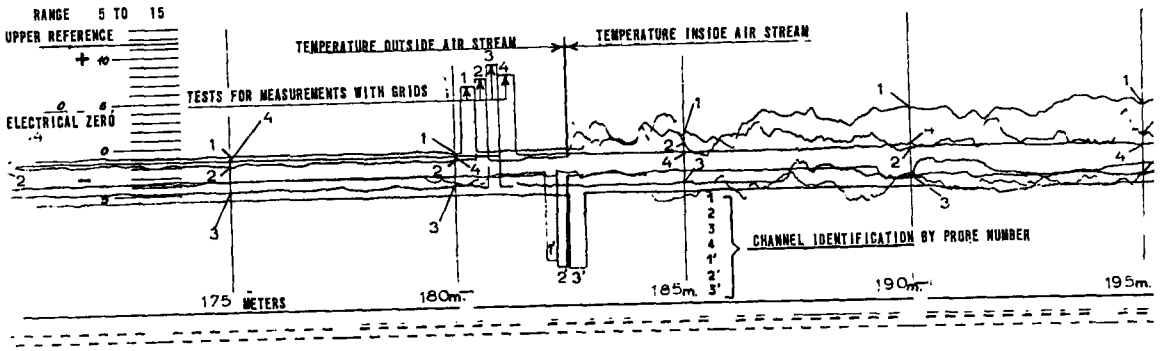


Figure 23. Temperature recording tape.

d) determination on the recordings of the temperature elevation bands. Consider the case when the measurement grid passes through the exhaust stream of a jet engine. During the passage, the temperature curves are affected by rapid frequency fluctuations of fairly large amplitude related to small-scale turbulence whose effect is not noted by the thermistors due to their excessively short response time. Since it was impossible to eliminate these fluctuations by averaging the curves at the risk of overloading the recorded tapes and thus making them unusable, the analysis was carried out while solely considering three values characteristic of the temperature elevation, these being specifically the following:

- The outer limits of the air stream. - On each curve the upper limit of the air stream has been indicated at the point where the first manifestation of an increase in temperature above the ambient was noted and the lower limit at the point of complete return to the ambient level.

- The limits of the band corresponding to a temperature increase of more than 2°C. - On the recordings, the trace of the isogain +2°C temperature curves coincided with the points starting at which (or up to which) the average temperature value was above the reference level of ambient temperature +2°C. This +2°C value was used

because it corresponds to the theoretical maximum temperature elevation of the air needed to produce evaporation of water droplets in the types of fog usually encountered in our area.

- The limits of the band corresponding to a temperature elevation of more than 5°C. These limits, determined as before, are of interest in locating the hottest part of the air stream.

e) recording the previous values on the diagrams. The preceding limits, each pertaining to one defined position in the measurement grid obtained by interpolation from the synchronization signals, were noted on diagrams of horizontal cross sections made at the reference levels.

f) drawing the curves. The curves corresponding to the limits of the air stream (or streams in the case of several engines) as well as the +2°C and +5°C temperature isogain curves were thus traced on horizontal drawings at the 3, 11, 19 and 27 m (10, 36, 62 and 89 ft.) reference levels after having being refined by superimposing the four levels. To give an idea of how difficult this work was, it took on the order of some 20 hours to analyze a single sequence.

4.4.2 Comparisons between temperature observations and measurements.

a) Observations on the ground. During the duration of one sequence, i.e., the exploration of the measurement platform by the crane, observers recorded the dimensions of the volume cleared on the ground. This gave a first indication of the coincidence of temperature measurements and observations, or the fact that the isogain +2°C temperature curve generally fell within the cleared zone (see Figure 16).

b) Observations in a vertical plane. The transition between the natural fog and the cleared volume passes through a heterogeneous zone in which can simultaneously be observed patches of fog and clear air. This zone corresponds to the turbulence mixture of hot air and fog at the borders of the air stream. The phenomenon is clearly obvious on the recordings between the "air stream limits" and "isogain +2°C" points: perturbation of the ambient level by short-lasting temperature elevations becomes more and more frequent towards the center of the air stream. It is difficult to see this zone on the ground and thus to improve the coincidence between the dimensions of the cleared volume and the temperature gains. Above ground, on the other hand, at points in the cleared zone and using the air-cooled thermistors as reference points, it was easier to note those points which were always, for a fixed crane position, in the clear air or cloudy air and those points which were temporarily affected either by patches of clear air or patches of fog. It was thus possible to approximately define the transition zone from fog to the cleared volume. When compared with the results of temperature measurements performed simultaneously,

these observations demonstrated that generally speaking the partially cleared zone fell within the limits of the air stream and the +2°C temperature isogain curve (see Figure 17).

4.4.3 Conclusion. Although more subjective than temperature measurements, observations during fog conditions made it possible to draw the following conclusions:

- The limits of the atmospheric volume affected by the hot air coincide with the so called "limits of the air stream."

- The +2°C temperature isogain bands correspond to totally cleared zones.

- The exact limits of the cleared volume can as a consequence, be considered to fall between the limits of the air stream and the +2°C temperature isogain, the latter being closer together up to the point of becoming identical on the side of the air stream from which the wind blows and further apart on the opposite side.

When studying the configuration of the air stream, it was decided to use as a limit for cleared volumes, the surface located at an equal distance from the limits of the air stream and from the surface defined by the +2°C temperature isogain. This surface was assigned the value +1°C.

Remark: Leeward of the air stream can be observed a "drag" effect which gives reason to anticipate that the cleared volume might be under estimated in that direction under certain conditions.

4.5 Determination of the configuration of the cleared volume. The main purpose of experimentation was the determiniation of the configuration of the volume cleared by the underground blower unit, a configuration which varies as a function of wind conditions. This determination was obtained by interpreting the experimental temperature curves drawn in horizontal planes at different levels. This was the goal of series 500 tests.

4.5.1 Interpreting procedure. The transition from experimental temperature curves to curves giving the envelope of the cleared volume only applies if a certain margin of uncertainty is granted, resulting from the following factors.

a) Measurements. The wind is not strictly constant during the duration of a given sequence. In addition, there can be a slight difference between the wind blowing over the measurement platform and the detected wind, the sensing device being located at a distance

of 300 to 400 meters (984 to 1312 ft.) from the platform. On the other hand, inaccuracy introduced by the measurement itself can be considered negligible in comparison with the uncertainty pertaining to the wind value.

b) Analysis. The analysis of the temperature measurements of necessity introduced a certain factor of subjectivity.

c) Limits of cleared volume. The outer limits of the cleared volume, when considered on the basis of temperature curves, will be likely to move either towards the limits of the air stream or towards the +2°C isogain curve as a function of fog characteristics (temperature, liquid water content and wind). Not enough data is available to clearly determine the influence of these factors.

d) Interpretation. Concerning interpretation, it was necessary to consider sequences corresponding to operation of the underground blower unit alone and simultaneous operation with the two above-ground units. In the latter instance, it was necessary to isolate the air stream from the underground unit (i.e., extrapolate some of its representative curves by taking into account, when necessary, the protective effect of the other units). Lastly, not every value of δ as a function of wind speed was covered by the experiment, and this made it necessary to rely on interpolation. To limit the influence of these factors of inaccuracy as much as possible, we chose a method of interpretation by averages providing the configuration of the most likely cleared volume. For each wind speed from zero to 4 m/s (9 mph) in steps of 1 m/s (2.2 m.p.h.), this configuration was represented in the form of horizontal cross sections at the 3, 11, 19 and 27 m (10, 36, 62, and 89 ft.) levels by assuming the direction of the air stream to be fixed and the direction of the wind to vary by intervals of 30°.

4.5.2 List of interpretive operations. Like the curves representing the air stream configuration, the experimental curves are characterized by the wind speed and value of angle δ. The transition from the first to the second was carried out using the following operations:

a) Choice of sequences. The experimental curves introduced into the interpretation correspond to those sequences whose list appears in Table 2. Since the symmetry of the air stream forced non-differentation between the positive and negative δ's, the experimental results gave the maximum number of possible combinations between absolute values of δ and the wind speed. Of 73 sequences retained, 65 were from the 500 series tests and eight from the series 600 tests.

TABLE 2. LIST OF SEQUENCES USED IN THE STUDY OF THE AIR STREAM CONFIGURATION

Wind Speed	δ	Sequence No.	Wind Speed	δ	Sequence No.	Wind Speed	δ	Sequence No.
0		539-01 & 539-02	2 m/sec (4.5 mph)	10	538-01	3 m/sec (6.7 mph)	80	519-06
0.5 m/sec (1.1 mph)	10	539-03		20	538-02		90	519-05 & 537-03
	20	538-03		40	538-06		120	520-04 & 532-09
	80	521-02		60	519-01		170	535-01
	90	521-03		70	524-02	3.5 m/sec (7.9 mph)	10	533-01
	130	522-04		80	521-05		50	532-06
1 m/sec (2.2 mph)	10	539-04		90	524-01		70	534-02
	30	538-05 & 540-01		100	524-03		80	532-05 & 532-07
	40	606-01		50	606-02 & 536-04		90	605-01
	60	540-02		60	537-06		100	605-03
	80	519-04 & 521-01		70	537-02		140	532-10
	100	540-05	2.5 m/sec (5.6 mph)	90	532-04	4 m/sec (9 mph)	20	533-02
	170	540-06		100	537-01		30	531-02
	180	540-04		110	532-02		70	605-02 & 533-03
1.5 m/sec (3.4 mph)	20	519-03		120	532-01		90	604-02
	60	521-04		130	537-04		180	535-02 & 535-03
	70	523-02		140	604-03	4.5 m/sec (10.1 mph)	40	611-01
	80	538-04		150	522-02		50	533-04
	100	522-05	3 m/sec (6.7 mph)	0	531-01		170	535-05
	110	520-01		50	537-05			
	120	522-01		60	532-03 & 534-01			
	170	523-03		70	532-08			

b) Drawing of experimental limits of cleared volumes. The next operation called for drawing on each diagram the +1°C curve defined as being located at an equal distance from the limits of the air stream and the +2°C curve.

c) Diagram of average curves. For each combination obtained for wind speed ν and angle δ, the experimental curves corresponding to the four reference levels (+1°C isogain curves) were drawn on the diagrams and when necessary the plots of these curves were averaged in similar instances. The following values of ν and δ were then considered:

ν = 0, 1 m/s, 2 m/s, 3 m/s, 4 m/s (0. mph, 2.2 mph, 1.5 mph, 6.7 mph, 9 mph)

δ = 0°, 30°, 60°, 90°, 120°, 150°, 180°

The average curve representing the cleared volume at each reference level and for each combination (ν_x, δ_y) was obtained by averaging the plots of the experimental curves, including those defined by:

δ_y, ν_x

δ_y, ν_x + 0.5 m/s (1.1 mph)
δ_y, ν_x - 0.5 m/s

δ_y + 10°, ν_x
δ_y + 10°, ν_x + 0.5 m/s
δ_y + 10°, ν_x - 0.5 m/s

δ_y - 10°, ν_x
δ_y - 10°, ν_x + 0.5 m/s
δ_y - 10°, ν_x - 0.5 m/s

Table 3 provides a list of sequences introduced in the determination of each family of average curves.

d) Representation of the configuration of the air stream. The average curves defined in this fashion were recorded on the diagrams. Each plane, relating to one wind speed and one reference level, includes one family of curves corresponding to the various values of δ assumed every 30° in the 0-360° sector. Since the initial direction of the air stream was fixed, this family of curves must fall within an envelope curve. It appeared this was virtually the case for wind speeds of 4 m/s (9 mph) but somewhat less accurate for lower wind speeds. We thus had to retouch some of the curves, the differences varying by an average 10 meters (33 ft.) and rarely 20 meters (66 feet) in order to obtain a homogeneous set in the plane from one reference level to the other for the same wind speed and from one wind speed to the other for the same reference level.

TABLE 3. LIST OF AVERAGE CURVES

Wind Speed	Avg. δ	Avg. Refer. Curve	List of Sequences Used
0		0-000	521-02, 521-03, 522-04, 538-03, 539-01, 539-02, 539-03
1 m/s (2.2 mph)	0	1-000	539-03 539-04
	30	1-030	519-03, 538-03, 538-05, 540-01, 606-01
	60	1-060	521-04, 523-02, 540-02
	90	1-090	519-04, 521-01, 521-02, 521-03, 522-05, 538-04, 540-05
	120	1-120	520-01, 522-01, 522-04
	150	1-150	1-120, 1-180,(1) 2-150
	180	1-180	523-03, 540-04, 540-06
2 m/s (4.5 mph)	0	2-000	538-01
	30	2-030	519-03, 538-02, 538-06
	60	2-060	519-01, 521-04, 523-02, 524-02, 536-04, 537-02, 537-06, 606-02
	90	2-090	521-05, 522-05, 524-01, 524-03, 532-04, 537-01, 538-04
	120	2-120	520-01, 522-01, 532-01, 532-02, 537-04
	150	2-150	522-02, 604-03
	180	2-180	523-03

Wind Speed	Avg. δ	Avg. Refer Curve	List of Sequences Used
3 m/s (6.7 mph)	0	3-000	531-01, 533-01
	30	3-030	2-030, 3-000 3-060, 4-030 (1)
	60	3-060	532-03, 532-06, 532-08, 534-01, 534-02, 536-04, 537-02, 537-05, 537-06, 606-02
	90	3-090	519-05, 519-06, 532-04, 532-05, 532-07, 537-01, 537-03, 605-01, 605-03
	120	3-120	520-04, 532-01, 532-02, 532-09, 537-04
	150	3-150	522-02, 532-10, 604-03
	180	3-180	535-01
4 m/s (9 mph)	0	4-000	535-02
	30	4-030	531-02, 533-02, 611-01
	60	4-060	532-06, 533-03, 533-04, 534-02, 605-02
	90	4-090	532-05, 532-07, 604-02, 605-01, 605-03
	120	4-120	3-120, 4-090, 4-150 (1)
	150	4-150	532-10
	180	4-180	535-02, 535-03, 535-05

(1) Curve obtained by interpolation of average curves.

The family of curves represented in the appendices were also obtained. These curves provide the average configuration of the air stream from the underground blower unit limited by the +1°C isogain, i.e.,, the most likely configuration of the volume cleared by the blower unit for values of δ falling between zero and 360° and for wind speeds between zero and 4 m/s (9 mph)

4.6 Snow and ice removal tests. Snow and ice removal tests produced the following results:

4.6.1 Range. Under favorable wind conditions, the snow and ice melting effect of the air stream from the underground blower unit was not felt beyond 80 to 100 meters (262 to 328 ft.) from the blower outlet grid.

4.6.2 Operating duration. The operating time required to obtain the melting of snow or ice covering a concrete slab at a distance of 50 meters (230 ft.) depends on the wind and temperature. Four minutes are required to melt a thin coating of ice when the temperature is in the neighborhood of 0°C. Ten to 30 minutes are required to melt a 2 cm (0.8 in.) layer of frozen ice at a temperature of -5°C.

Conclusion. It would appear that a Turboclair installation is of limited value in removing ice or snow from a runway because of the limited range and length of time required to produce good results. Since the time of these tests, its value has further been reduced through installation of the Bertin turbo-snow remover.

4.7 Fog measurements. Measurements of fog characteristics were covered in a detailed report by the Bertin Company (report on 1967-68 testing which included the measurement of fog characteristics).

4.7.1 Measuring equipment. The following equipment was used:

a) liquid water collecting device - measure the quantity of liquid water contained in the fog through deposit of the water droplets on a fiberglass filter through which a given volume of air is allowed to pass.

b) photogranulometer - optical determination of number droplets per unit volume.

c) impact device - determination of granulometric spectrum of fog (number, distribution by size and dimensions of droplets)

d) conventional ground measurements - weather conditions, pressure, temperature and relative humidity.

During the prototype phase, the first three units were especially designed and constructed by the Bertin Company.

4.7.2 Tests performed. Fairly extensive measurements of fog characteristics were performed during six texts under fog conditions.

4.7.3 Results. Interpretation of results consisted of establishing experimental curves relating visibility with the liquid water content and the number of droplets per cubic cm given either by the photogranulometer or the impact device. Despite a limited number of measurements and trial and error procedures inherent in the experimental nature of the equipment, results obtained were coherent. In specific, they confirmed the wide variability in fog characteristics pertaining to a given situation.

Conclusion. These measurements were of a purely speculative nature in respect to the experimentation. In effect, the influence on the determination of the configuration of the cleared volume of the physical parameters typifying the fog comes second after the wind and is virtually impossible to test due to an inability to isolate these different parameters. However, they are still of considerable interest since they influence the development of fog dispersal methods using seeding procedures. Furthermore, the performance anticipated from an operational Turboclair installation will apply to average fog situations. At the outset, at least, there will be no point in coupling measurements of fog characteristics with operation of the dispersal method if only to permit the analysis of counterperformance obtained during fog conditions not normally encountered in our area (for example, fogs with a high liquid water content). These measurements would also be of value to installations to be built in areas where fog characteristics are very different from those encountered in the area around Paris.

5. CONCLUSION: DEFINITION OF AN OPERATIONAL INSTALLATION

The experimentation just described marked the completion of the general test program being developed since 1958 by the Paris Airport and the Bertin Company. Its final objective is the installation of equipment using the Turboclair method along runways. The definition of this installation will include three processes specific to the method, these being:

- design of the underground blower unit
- installation of underground blower units
- the program to orient the air streams as a function of the wind

5.1 Definition of the underground blower unit. It can be assumed the unit must guarantee the program's good reliability. The level of turbulence has been decreased as far as possible without reducing the initial speed of the air stream. The problem of ground erosion, which raised some concern in respect to its effect on the cost of the installation, can be dealt with at relatively low cost. The noise factor, not directly covered in the testing, is still of concern. Although the sound level of the underground blower unit can be sizeably decreased by sound reduction devices, choice of a site for the installation of an operational facility

must take into account the possible proximity of an urban area. Evaluation of the discomfort caused by the noise is purely subjective. It can thus be anticipated there will be no cause for discomfort if the noise generated by the facility combines with noises normally recorded in the area around an airport with the exception of direct overhead flight. This can contribute to determining the noise level to be considered a maximum. This means the facility will probably be operated intermittently with a drop in engine speed between landings. This procedure will be determined in the future. At the present time, the last problem now being studied is the design of the frangible or flexible directional plates capable of withstanding the temperature and thrust of the air stream.

5.2 Location of underground blower units. Location of the underground units will be the most difficult phase of the operation. In effect, this is a necessary step to be taken between experimentation and application of the process in question. However, certain risks are involved despite precautions to be taken ahead of time. Furthermore, installation of the units will be irreversible and thus constitutes a determining factor in the success of the entire project. It is planned to determine their location as follows:

5.2.1 Basic data. Basic data will be supplied by curves indicating the configuration of the cleared volume as they result from interpretation of the temperature measurements.

5.2.2 Preliminary operations. The first operation will consist of outlining those portions of the runway over which the cleared volume will reach a specific reference level as a function of aircraft path either at the 27 meter (89 ft.) level on the approach side, the 19 meter (62 ft.) level above the touchdown area or the 11 meter (36 ft.) level in the rolling zone. For each engine, the configuration of the cleared volume to be considered will be that given by the curves corresponding to the reference level to be reached over the portion of runway affected by this volume.

5.2.3 Approximate value of orientation of underground blower units. For each speed and angle (varying in 30° steps) of the wind with the runway centerline axis will be determined the optimum values for orientation of the air stream and the distance of the underground blower unit from the runway giving the greatest cleared volume above the runway for each reference level. This determination will take into account the fact that the component of the speed of the hot air along the axis of the runway must be directed towards the approach in order to avoid having the aircraft land downwind.

5.2.4 Special installation of underground blower units. In order to handle all wind conditions, at least above the rolling zone, a facility must consist of two rows of underground blower units located on each side of the runway. Since this is valid for a preoperational version, a facility will be considered which includes a single row of engines placed on the side from which dominating winds blow during fog conditions. In design of this facility, only wind blowing from that side of the runway where the units are located will be taken into account, the limit being wind parallel to the runway.

Starting with the previous determinations, for each wind condition will be defined the corresponding optimum location of the underground units and the direction of the air stream from each unit by juxtaposition of the limits of the cleared volumes on the reference levels to be considered. Thus, a series of locations specific to each wind condition (speed and direction) will be obtained.

5.2.5 Final action. The location will be noted of the convergence of these specific locations on a single or typical location with readjustment, when necessary, of air stream direction. For each unit the best compromise must be found between the maximum dimensions of the cleared zone over the runway and the location of the center of this zone, which must be as close as possible to the centerline axis of the runway. Furthermore, a change in wind speed or direction must not produce any discontinuity in the orientation of the air streams. Wind conditions for which the typical location will differ considerably from the specific corresponding location will be examined in detail. The only risk which might then be encountered will be the presence of patches of fog over the runway. This drawback will be evaluated as a function of the decrease in foreseeable visibility and probability of such situations. It could possibly lead to changes in the typical location. Before finalizing the location, comparative studies will be made with test results obtained since 1958 at installations using several blower units.

Specifically, it will be valuable to determine the influence of the effect or mutual air stream protection, the "drag" effect and the possible effects of accumulation of hot air in one direction, these effects possibly being favorable in the preceding limiting instances.

5.3 Orientation of underground blower units. The definition of the program to orient the underground blower units as a function of the wind will be combined with planning for their location. Once they have been installed this program will be refined. Sensitivity of the system to the wind already makes it possible to anticipate that orientation of the blower outlet grids, unit by unit, must be directly controlled by one or several wind direction indicators.

5.4 General conclusion. This last phase of development of the Turboclair method made it possible to base the method on sound experimental data and thus draw closer to the definition of an operational installation. It is now felt that this facility can be designed without any risk of committing basic mistakes. Nonetheless, it must not be forgotten that this method is still in the experimental stage and that some uncertainties have yet to be removed, specifically those concerning an operational installation. Such uncertainties include turbulence and the possible effects of local changes in the vertical thermal gradient leading to a rise of hot air at the level of the device capable of directing fog towards the runway. The influence of these phenomena can only be studied once an operational installation is in service.

APPENDIX A

List of Series 300 Tests

Conventions:

α = half angle of opening of directional plates

engine position:

A = advanced

R = withdrawn

cross section:

L = longitudinal

T = transversal

Observations:

A = sequence cancelled

ND = sequence not analyzed

LIST OF SERIES 300 TESTS

DATE	SEQUENCE	WEATHER CONDITIONS: WIND SPEED (m/s)	WEATHER CONDITIONS: WIND DIRECTION (°)	WEATHER CONDITIONS: TEMP. °C	UNDERGROUND BLOWER UNIT: ENGINE OPER. SPEED	UNDERGROUND BLOWER UNIT: BLOWER OUT-LET GRID ORIENTATION	UNDERGROUND BLOWER UNIT: DILUTION RATE	UNDERGROUND BLOWER UNIT: DIRECT. PLATE TYPE	UNDERGROUND BLOWER UNIT: DIRECT. PLATE α (°)	UNDERGROUND BLOWER UNIT: ENGINE POSITION	CROSS SEC.	NOTES
10/13/65	301-01	1.5	80	+20	8000	160	1.33	6	6	R	L	
"	301-02	2	125	+20	"	150	"	"	6	"	T	
"	301-03	2	105	+20	"	"	"	"	8	"	T	
"	301-04	2	150	+22	"	"	"	"	10	"	T	
"	301-05	2	145	+22.5	"	"	"	"	12	"	T	
"	301-06	2.5	160	+23	"	"	"	"	14	"	T	
"	301-07	2	125	+23	"	"	"	"	14	"	T	
"	301-08	1.5	120	+24.5	"	"	"	"	12	"	L	
"	301-09	0.5	110	+25.5	"	"	"	"	10	"	L	
"	301-10	0.5	25	+25	"	"	"	"	8	"	L	
"	301-11	1	125	+25	"	"	"	"	6	"	L	
"	302-01	2	140	+20	"	"	"	7	6	"	L	
"	302-02	2	130	+19.5	"	"	"	"	10	"	L	
"	302-03	2	90	+19	"	"	"	"	14	"	L	
"	302-04	2	80	+18	"	"	"	"	14	"	T	
"	302-05	1.5	80	+17.5	"	"	"	"	10	"	T	
"	302-06	1.5	85	+17	"	"	"	"	6	"	T	
1/4/66	303-01	2.5	120	+4	"	"	"	1	6	A	T	
"	303-02	2.5	120	+4.2	"	"	"	"	10	"	T	
"	303-03	2	110	+4.2	"	"	"	"	14	"	T	
"	303-04	2	150	+5.5	"	"	"	4	14	"	T	
"	303-05	2	150	+5.7	"	"	"	"	10	"	T	
"	303-06	1.5	140	+6	"	"	"	"	6	"	T	
"	303-07	2	140	+6.2	"	"	"	"	6	"	L	
"	303-08	2	150	+5.7	"	"	"	"	10	"	L	
"	303-09	2	150	+5.5	"	"	"	"	14	"	L	
2/1/66	304-01	1.5	160	+9.5	"	"	"	5	0	"	L	
"	304-02	0		+9.5	"	"	"	"	6	"	L	
"	304-03	0		+9.5	8150	"	"	"	6	"	L	
"	304-04	1.5	160	+9.5	8000	"	"	"	14	"	L	

LIST OF SERIES 300 TESTS

DATE	SEQUENCE	WEATHER CONDITIONS: WIND SPEED (m/s)	WEATHER CONDITIONS: WIND DIRECTION (°)	WEATHER CONDITIONS: TEMP. °C	UNDERGROUND BLOWER UNIT: ENGINE OPER. SPEED	UNDERGROUND BLOWER UNIT: BLOWER OUT-LET GRID ORIENTATION	UNDERGROUND BLOWER UNIT: DILUTION RATE	UNDERGROUND BLOWER UNIT: DIRECT. PLATE TYPE	UNDERGROUND BLOWER UNIT: DIRECT. PLATE α (°)	UNDERGROUND BLOWER UNIT: ENGINE POSITION	CROSS SEC.	NOTES
2/1/66	304-05	1	170	+9.5	8000	150	1.33	5	14	A	T	
"	304-06	1.5	170	"	"	"	"	"	6	"	"	
"	304-07	2	160	+10.2	"	"	"	"	0	"	"	
3/2/66	305-01	4	160	+10	7000	"	"	"	6	"	L	ND
"	305-02	4	170	"	7250	"	"	"	"	"	"	"
"	305-03	4	160	"	7500	"	"	"	"	"	"	"
"	305-04	4.5	150	"	7750	"	"	"	"	"	"	"
"	305-05	4	160	"	8000	"	"	"	"	"	"	"
"	305-06	3	170	"	8050	"	"	"	"	"	"	"
"	305-07	4	160	"	8150	"	"	"	"	"	"	"
4/1/66	306-01	3	180	+7.5	8000	"	1.20	"	"	"	T	
"	306-02	3	180	+8	"	"	"	"	12	"	"	
"	306-03	3.5	180	+8.5	"	"	"	"	"	"	"	
"	306-04	3	170	+9	8150	"	"	"	"	"	"	
"	306-05	3.5	190	"	8000	"	"	"	6	"	"	
"	306-06	3.5	190	"	8150	"	"	"	"	"	"	
"	306-07	3.5	190	+10.5	8000	"	"	"	0	"	"	
"	306-08	3.5	180	"	8150	"	"	"	"	"	"	
4/12/66	307-01	3	170	+9	8000	"	"	4	"	"	"	
"	307-02	3	180	"	8150	"	"	"	"	"	"	
"	307-03	2.5	170	+10.5	8000	"	"	"	6	"	"	
"	307-04	2.5	160	"	8150	"	"	"	"	"	"	
"	307-05	2.5	160	+11.5	8000	"	"	"	"	"	L	
"	307-06	2	170	+12	8150	"	"	"	"	"	"	
"	307-07	3	170	+12.5	8000	"	"	"	0	"	"	
"	307-08	3	180	"	8150	"	"	"	"	"	"	
2/24/67	331-01	3	160	+3.5	"	"	"	8	6	"	"	
"	331-02	3.5	160	"	"	"	"	"	"	"	T	
"	331-03	4	160	+4	"	"	"	"	"	"	"	

NOTE: Tests 301 to 307: Type A grid
Test 331 : Type B grid

APPENDIX B

List of Series 500 Tests

Conventions:

α = half angle of opening of directional plates

δ = angle formed by the wind and the airstreams as measured in the inverse trigonometric direction using the airstream as the origin.

Observations:

A = sequence cancelled

ND = sequence not analyzed

LIST OF SERIES 500 TESTS, FIRST SERIES, GRID A

DATE	SEQUENCE	WEATHER CONDITIONS: WIND SPEED (m/s)	WIND DIR (°)	TEMP. °C	UNDERGROUND BLOWER UNIT: BLOWER OUTLET GRID ORIENT.	δ	DILUTION RATE	DIRECT. PLATE TYPE	α (°)	ORIENT. OF ABOVE-GROUND ENGINES 3	5	ENGINE OPER. SPEED	NOTES
3/4/65	501-01	3.5	200	+4	150	+50	1.33	3	12	HS	HS	8000	ND
"	501-02	2.5	190	+4	120	+70	1.33	3	12	HS	HS	8000	ND
"	501-03	3	190	+4	180	+10	1.33	3	12	HS	HS	8000	ND
"	501-04	4.5'	200	+4	210	-10	1.33	3	12	HS	HS	8000	ND
3/8/65	502-01	2	280	+9	150	+130	1.33	3	14	HS	HS	8000	ND
"	502-02	2	270	+9	150	+120	1.33	3	14	150	HS	8000	
"	502-03	2	260	+9	150	+110	1.33	3	14	150	HS	7000	ND
"	502-04	2.5	280	+9	150	+130	1.33	3	14	150	HS	7500	ND
3/9/65	503-01	2.5	70	+3	120	-50	1.33	3	14	HS	HS	8000	
"	503-02	2.5	70	+3	150	-80	1.33	3	14	HS	HS	8000	
3/22/65	504-01	3	120	+5	150	-30	1.33	5	12	HS	HS	8000	
"	504-02	2.5	140	+5	150	-10	1.33	5	12	HS	HS	7000	
"	504-03	3	140	+5	150	-10	1.33	5	12	HS	HS	6500	
"	504-04	4.5	150	+5	120	+30	1.33	5	12	HS	HS	8000	
"	504-05	4	160	+5	180	-20	1.33	5	12	HS	HS	8000	
4/2/65	505-01	1.5	80	+11	170	-90	1.33	7	6	HS	HS	8000	ND
"	505-02	2.5	40	+11	90	-50	1.33	7	6	HS	HS	8000	ND
"	505-03	2.5	50	+11	200	-150	1.33	7	6	HS	HS	8000	ND
"	505-04	2.5	50	+11	150	-100	1.33	7	6	150	HS	8000	ND
"	505-05	2.5	60	+11	150	-90	1.33	7	6	150	150	8000	
"	505-06	2.5	20	+11	150	-130	1.33	7	6	HS	HS	8000	ND
4/5/65	506-01	1	290	+10	180	+110	1.33	7	6	HS	HS	8000	
"	506-02	0.5	240	+10	150	+90	1.33	6	6	HS	HS	8000	
"	506-03	1	210	+10	150	+60	1.33	6	6	HS	HS	7000	
4/14/65	507-01	1.5	270	+12	150	+120	1.33	7	6	150	150	8000	
"	507-02	2.5	240	+12	110	+130	1.33	7	6	150	150	8000	
4/30/65	508-01	4	100	+12	150	-50	1.33	7	8	150	150	8000	ND
"	508-02	4	90	+12	150	-60	1.33	7	8	150	150	6000	ND
"	508-03	4	120	+12	150	-30	1.33	7	8	150	150	7000	ND
5/11/65	509-01	4	60	+14	150	-90	1.33	7	8	150	150	8000	
"	509-02	4	40	+14	150	-110	1.33	7	8	150	150	8000	ND

LIST OF SERIES 500 TESTS, FIRST SERIES, GRID A

DATE	SEQUENCE	WEATHER CONDITIONS			UNDERGROUND BLOWER UNIT			DIRECT. PLATE		ORIENT. OF ABOVE-GROUND ENGINES		ENGINE OPER. SPEED	NOTES
		WIND SPEED (m/s)	WIND DIR (°)	TEMP. °C	BLOWER OUTLET GRID ORIENT.	δ	DILUTION RATE	TYPE	α (°)	3	5		
5/11/65	509-03	4	60	+14	150	-90	1.33	7	10	150	150	8000	ND
5/11/65	509-04	5.5	70	+14	150	-80	1.33	7	12	150	150	8000	ND
5/12/65	510-01	2.5	80	+15.5	130	-50	1.33	7	12	130	130	8000	ND
5/12/65	510-02	4	110	+16.8	130	-20	1.33	7	12	130	130	7500	ND
5/12/65	510-03	4.5	100	+18.2	130	-30	1.33	7	6	130	130	8000	ND
5/12/65	510-04	4.5	110	+19.6	130	-20	1.33	7	6	130	130	7500	ND
5/26/65	511-01	2	260	+19.5	130	+130	1.33	6	6	130	130	8000	ND
5/26/65	511-02	2.5	270	+19.5	130	+140	1.33	6	6	130	130	8000	A
6/1/65	512-01	2	110	+13	120	-10	1.33	6	6	120	120	8000	ND
6/1/65	512-02	3.5	120	+13	120	0	1.33	6	6	120	120	8000	ND
6/11/65	513-01	3	40	+22	210	-170	1.33	6	6	HS	HS	8000	ND
6/11/65	513-02	3	30	+22	180	-150	1.33	6	6	HS	HS	8000	ND
6/11/65	513-03	3	40	+22	180	-140	1.33	6	6	HS	HS	8000	ND
6/11/65	513-04	2.5	30	+22	150	-120	1.33	6	6	HS	HS	8000	ND
11/4/65	514-01	2	330		150	180	1.33	6	12	HS	HS	8000	A
11/4/65	514-02	3	340		120	-140	1.33	6	12	HS	HS	8000	A
11/4/65	514-03	3.5	20		90	-70	1.33	6	12	HS	HS	8000	A
11/4/65	514-04	3.5	20		100	-80	1.33	6	12	HS	HS	8000	A
11/4/65	514-05	2.5	10		110	-90	1.33	6	12	HS	HS	8000	A
11/4/65	514-06	2.5	20		120	-100	1.33	6	12	HS	HS	8000	A
11/4/65	514-07	2.5	20		130	-110	1.33	6	12	HS	HS	8000	A
11/4/65	514-08	3.5	30		150	-120	1.33	6	12	HS	HS	8000	A
1/24/65	515-01	3	170	+5	90	+80	1.33	6	10	HS	HS	8150	A
1/24/66	515-02	2	190	+5.5	90	+100	1.33	6	10	90	HS	8150	ND
1/24/66	515-03	2	180	+5.5	90	+90	1.33	6	10	90	HS	8050	ND
1/24/66	515-04	3	190	+6	90	+100	1.33	6	10	HS	HS	8150	ND
1/24/66	515-05	3.5	200	+6.5	90	+110	1.33	6	10	HS	HS	7850	ND
1/24/66	515-06	3.5	200	+6.5	90	+110	1.33	6	10	HS	HS	7600	ND
2/3/66	516-01	1.5	240	+6.5	90	+150	1.33	6	10	HS	HS	8000	ND
2/3/66	516-02	2.5	250	+6.5	150	+100	1.33	6	10	HS	HS	8000	ND

LIST OF SERIES 500 TESTS, FIRST SERIES, GRID A

DATE	SEQUENCE	WEATHER CONDITIONS			UNDERGROUND BLOWER UNIT			DIRECT. PLATE		ORIENT. OF ABOVE-GROUND ENGINES		ENGINE OPER. SPEED	NOTES
		WIND SPEED (m/s)	WIND DIR (°)	TEMP. °C	BLOWER OUTLET GRID ORIENT.	δ	DILUTION RATE	TYPE	α (°)	3	5		
2/3/66	516-03	2.5	250	+7	130	+120	1.33	6	10	HS	HS	8000	ND
2/3/66	516-04	2.5	240	+7.5	90	+150	1.33	6	10	HS	HS	8000	ND
4/27/66	517-01	2	210	+18	90	+130	1.20	7	6	90	90	8000	ND
4/27/66	517-02	2.5	200	+18	90	+110	1.20	7	6	90	90	8000	ND
4/27/66	517-03	3.5	180	+19	90	+90	1.20	7	6	90	90	8000	ND
4/27/66	517-04	4.5	170	+19	90	+80	1.20	7	6	90	90	8000	ND
5/3/66	518-01	2	180	+18.5	90	+90	1.20	7	6	90	90	8000	ND
5/3/66	518-02	2.5	180	+18.5	90	+90	1.20	7	6	90	90	8000	ND
5/3/66	518-03	2.5	200	18.5	90	+110	1.20	7	6	90	90	8000	ND
5/3/66	518-04	1.5	220	19.5	150	+70	1.20	7	6	150	150	8000	ND
5/3/66	518-05	1	230	20	150	+80	1.20	7	6	150	150	8000	ND
5/3/66	518-06	1.5	210	22	180	+30	1.20	7	6	180	180	8000	ND
5/12/66	519-01	2	210	13.5	150	+60	1.20	7	6	150	150	8150	
5/12/66	519-02	1.5	170	14.5	150	+20	1.20	7	6	150	150	8150	ND
5/12/66	519-03	1.5	170	16	150	+20	1.20	7	6	150	150	8150	
5/12/66	519-04	1	230	17.5	150	+80	1.20	7	6	150	150	8150	
5/12/66	519-05	3	180	13.5	90	+90	1.20	7	6	90	90	8150	
5/12/66	519-06	3	170	13.5	90	+80	1.20	7	6	90	90	8150	
5/13/66	520-01	1.5	200	15	90	+110	1.20	7	6	90	90	8150	
5/13/66	520-02	2.5	230	15	90	+140	1.20	7	6	90	90	8150	ND
5/13/66	520-03	2	250	16	120	+130	1.20	7	6	120	120	8150	ND
5/13/66	520-04	3	240	16	120	+120	1.20	7	6	120	120	8150	
5/18/66	521-01	1	40	17.5	120	-80	1.20	7	6	120	120	8150	
5/18/66	521-02	0.5	40	19	120	-80	1.20	7	6	120	120	8150	
5/18/66	521-03	0.5	60	19	150	-90	1.20	7	6	150	150	8150	
5/18/66	521-04	1.5	210	19	150	+60	1.20	7	6	150	150	8150	
5/18/66	521-05	2	230	19.5	150	+80	1.20	7	6	150	150	8150	
5/18/66	521-06	2.5	220	19.5	150	+70	1.20	7	6	150	150	8150	ND
5/24/66	522-01	1.5	210	14.5	90	+120	1.20	7	6	90	90	8150	

LIST OF SERIES 500 TESTS, FIRST SERIES; GRID A

DATE	SEQUENCE	WEATHER CONDITIONS: WIND SPEED (m/s)	WEATHER CONDITIONS: WIND DIR (°)	WEATHER CONDITIONS: TEMP. °C	UNDERGROUND BLOWER UNIT: BLOWER OUTLET GRID ORIENT.	UNDERGROUND BLOWER UNIT: δ	UNDERGROUND BLOWER UNIT: DILUTION RATE	DIRECT. PLATE: TYPE	DIRECT. PLATE: α (°)	ORIENT. OF ABOVE-GROUND ENGINES: 3	ORIENT. OF ABOVE-GROUND ENGINES: 5	ENGINE OPER. SPEED	NOTES
5/24/66	522-02	2.5	240	+14.5	90	+150	1.20	7	6	90	90	8150	
5/24/66	522-03	3.5	245	+15.5	75	+170	1.20	7	6	75	75	8150	ND
5/24/66	522-04	0.5	205	+16	75	+130	1.20	7	6	75	75	8150	
5/24/66	522-05	1.5	175	+16.5	75	+100	1.20	7	6	75	75	8150	
5/24/66	522-06	2.5	205	+17	75	+130	1.20	7	6	75	75	8150	ND
6/2/66	523-01	1	285	+13.5	75	+110	1.20	7	6	75	75	8150	ND
6/2/66	523-02	1.5	220	+15.5	150	+70	1.20	7	6	150	150	8150	
6/2/66	523-03	1.5	320	+16.5	150	+170	1.20	7	6	150	150	8150	
6/2/66	523-04	2	250	+17	150	+100	1.20	7	6	150	150	8150	A
6/3/66	524-01	2	60	+19	150	-90	1.20	7	6	150	150	8150	
6/3/66	524-02	2	80	+19.5	150	-70	1.20	7	6	150	150	8150	
6/3/66	524-03	2	80	+20.5	150	-100	1.20	7	6	180	180	8150	
6/3/66	524-04	2	70	+20.5	180	-110	1.20	7	6	180	180	8150	ND
6/3/66	524-05	3	80	+20.5	180	-100	1.20	7	6	180	180	8150	ND
6/3/66	524-06	2	110	+21	180	-70	1.20	7	6	180	180	8150	ND

LIST OF SERIES 500, SECOND SERIES - GRID B

DATE	SEQUENCE	WEATHER CONDITIONS			UNDERGROUND BLOWER UNIT			DIRECT. PLATE		ORIENT. OF ABOVE-GROUND ENGINES		ENGINE OPER. SPEED	NOTES
		WIND SPEED (m/s)	WIND DIR (°)	TEMP. °C	BLOWER OUTLET GRID ORIENT.	δ	DILUTION RATE	TYPE	α (°)	3	5		
2/24/67	531-01	3	150	+1.5	150	0	1.20	8	6	HS	HS	8150	
2/24/67	531-02	4	150	+2	120	+30	1.20	8	6	HS	HS	8150	
3/3/67	532-01	2.5	270	+4.5	150	+120	1.20	8	6	HS	HS	8100	
3/3/67	532-02	2.5	260	+4.5	150	+110	1.20	8	6	HS	HS	8100	
3/3/67	532-03	3	210	+5.5	150	+60	1.20	8	6	HS	HS	8100	
3/3/67	532-04	2.5	210	+6	120	+90	1.20	8	6	HS	HS	8100	
3/3/67	532-05	3.5	230	+5.5	150	+80	1.20	8	6	150	150	8100	
3/3/67	532-06	3.5	200	+6	150	+50	1.20	8	6	150	150	8100	
3/3/67	532-07	3.5	200	+7.5	120	+80	1.20	8	6	120	120	8100	
3/3/67	532-08	3	190	+8	120	+70	1.20	8	6	120	120	8100	
3/3/67	532-09	3	210	+8	90	+120	1.20	8	6	HS	HS	8100	
3/3/67	532-10	3.5	210	+9	70	+140	1.20	8	6	HS	HS	8100	
3/7/67	533-01	3.5	110	+8.5	120	-10	1.20	8	6	120	120	8100	
3/7/67	533-02	4	100	+8.5	120	-20	1.20	8	6	120	120	8100	
3/7/67	533-03	4	110	+9	180	-70	1.20	8	6	HS	HS	8100	
3/7/67	533-04	4.5	130	+9.5	180	-50	1.20	8	6	180	180	8100	
3/7/67	533-05	5	130	+10	180	-50	1.20	8	6	180	180	8100	
3/15/67	534-01	3	240	+6.5	180	+60	1.20	8	6	180	180	8100	
3/15/67	534-02	3.5	220	+8	150	+70	1.20	8	6	150	150	8100	
3/15/67	534-03	5	210	+8.5	150	+60	1.20	8	6	150	150	8100	
4/13/67	535-01	3	340	+9	150	-170	1.20	8	6	150	150	8100	
4/13/67	535-02	4	330	+10	150	180	1.20	8	6	150	150	8100	
4/13/67	535-03	4	330	+10.5	150	180	1.20	8	6	HS	HS	8100	
4/13/67	535-04	4.5	350	+10.5	120	-130	1.20	8	6	HS	HS	8100	
4/13/67	535-05	4.5	340	+10.5	150	-170	1.20	8	6	HS	HS	8100	
4/13/67	535-06	4	350	+11.5	120	-130	1.20	8	6	HS	HS	8100	
4/24/67	536-01	2.5	350	+12.5	150	-160	1.20	8	6	150	150	8100	ND
4/24/67	536-02	2.5	320	+12.5	150	+170	1.20	8	6	150	150	8100	ND
4/24/67	536-03	3	30	+13.5	150	-120	1.20	8	6	150	150	8100	ND

LIST OF SERIES 500, SECOND SERIES GRID B

DATE	SEQUENCE	WEATHER CONDITIONS: WIND SPEED (m/s)	WEATHER CONDITIONS: WIND DIR (°)	WEATHER CONDITIONS: TEMP. °C	UNDERGROUND BLOWER UNIT: BLOWER OUTLET GRID ORIENT.	UNDERGROUND BLOWER UNIT: δ	UNDERGROUND BLOWER UNIT: DILUTION RATE	DIRECT. PLATE: TYPE	DIRECT. PLATE: α (°)	ORIENT. OF ABOVE-GROUND ENGINES: 3	ORIENT. OF ABOVE-GROUND ENGINES: 5	ENGINE OPER. SPEED	NOTES
4/24/67	536-04	2.5	100	+14	150	-50	1.20	8	6	150	150	8100	
5/8/67	537-01	2.5	250	+12	150	+100	1.20	8	6	150	150	8100	
"	537-02	2.5	220	+12.5	150	+70	1.20	8	6	150	150	8100	
"	537-03	3	240	+12.5	150	+90	1.20	8	6	150	150	8000	
"	537-04	2.5	250	+13	120	+130	1.20	8	6	HS	HS	8000	
"	537-05	3	230	+13.5	180	+50	1.20	8	6	HS	HS	8000	
"	537-06	2.5	210	+14	150	+60	1.20	8	6	HS	HS	8100	
5/9/67	538-01	2	140	+13.5	150	-10	1.20	8	6	150	150	8100	
"	538-02	2	130	+13.5	150	-20	1.20	8	6	150	150	8100	
"	538-03	0.5	130	+14	150	-20	1.20	8	6	HS	HS	8100	
"	538-04	1.5	180	+15	100	+80	1.20	8	6	HS	HS	8100	
"	538-05	1	150	+15.5	180	-30	1.20	8	6	HS	HS	8100	
"	538-06	2	140	+15.5	180	-40	1.20	8	6	180	180	8100	
9/28/67	539-01	0		+16	150		1.20	8	6	HS	HS	8100	
"	539-02	0		+16.5	90		1.20	8	6	HS	HS	8100	
"	539-03	0.5	130	+18	120	+10	1.20	8	6	HS	HS	8100	
"	539-04	1	130	+19	120	+10	1.20	8	6	HS	HS	7000	
6/7/68	540-01	1	150	+16	120	+30	1.20	8	6	HS	HS	8100	
"	540-02	1	180	+22	120	+60	1.20	8	6	120	120	8100	
"	540-03	1.5	340	+21	120	-140	1.20	8	6	120	120	3000	
"	540-04	1	270	+21	90	180	1.20	8	6	120	120	8100	
"	540-05	1	250	+21.5	150	+100	1.20	8	6	120	120	8100	
"	540-06	1	275	+20	105	+170	1.20	8	6	90	120	8100	

APPENDIX C

List of Series 600 Tests

Conventions:

α = half angle of opening of directional plates

δ = angle formed by the wind and airstreams as measured in the inverse trigonometric direction using the airstream as the origin.

Observations:

A = sequence cancelled

T = sequence with temperature measurements

(ND) = sequence not analyzed

LIST OF SERIES 600 TESTS, FIRST SERIES, GRID A

DATE	SEQUENCE	WEATHER CONDITIONS				UNDERGROUND BLOWER UNIT					ORIENTATION OF ABOVE-GRND. ENGINES		ENGINE OPERATIONAL SPEED	NOTES
		WIND		VISIBILITY (m)	TEMP. °C	GRID ORIENTATION	δ	DILUTION RATE	DIRECTIONAL PLATES					
		SPEED (m/s)	DIR.						TYPE	α(°)	3	5		
9/15/65	601-01	1.5	190	100	+13	150/120	+40/+70	1.33	7	6	HS	HS	8150	
9/23/65	602-01	0.5	140	100	+7	150	-10	1.33	7	6	HS	HS	8150	
"	602-02	0.5	140	100	+7	120	+20	1.33	7	6	HS	HS	8150	
"	602-03	0.5	145	100	+7	105	+40	1.33	7	6	HS	HS	8150	
"	602-04	0.5	145	100	+7	95	+50	1.33	7	6	HS	HS	8150	
"	602-05	0.5	140	100	+7	150	-10	1.33	7	6	HS	HS	8150	
"	602-06	1.5	140	100	+7	150	-10	1.33	7	6	150	HS	8150	
"	602-07	3.5	180	100	+7	150	+30	1.33	7	6	150	HS	8150	
10/14/65	603-01	2	155	175	+6	105	+50	1.33	6	6	HS	HS	8000	T
"	603-02	1.5	145	175	+6	105	+40	1.33	6	6	HS	HS	8000	T (ND)
"	603-03	2	155	175	+6	195	-40	1.33	6	6	HS	HS	8000	T (ND)
"	603-04	1.5	170	175	+6	150	+20	1.33	6	6	HS	HS	8000	T (ND)
"	603-05	2	145	175	+6.8	105	+40	1.33	6	6	105	105	8000	A
"	603-06	2	130	175	+6.8	90	+40	1.33	6	6	105	105	8000	T (ND)
"	603-07	2	140	175	+6.8	90	+50	1.33	6	6	90	90	8000	T (ND)
10/27/65	604-01	3.5	180	100	+10	90	+90	1.33	6	10	HS	HS	8000	
"	604-02	4	180	100	+10	90	+90	1.33	6	10	HS	HS	8000	T
"	604-03	2.5	220	100	+10	80	+140	1.33	6	12	HS	HS	8000	T
2/4/66	605-01	3.5	180	500	+4	90	+90	1.33	6	10	HS	HS	8150	T
"	605-02	4	160	500	+4	90	+70	1.33	6	10	90	HS	8150	T
"	605-03	3.5	160	>1000	+4	60	+100	1.33	6	10	60	HS	8150	T
2/18/66	606-01	1.2	110	100	+6.5	150	-40	1.33	6	6	150	150	8150	T
"	606-02	2.5	140	150	+7.5	90	+50	1.33	6	6	90	90	8150	T
9/11/66	607-01	1	100	175	+15.5	150	-50	1.20	7	6	HS	HS	8150	
"	607-02	2	100	175	+15.5	210	-110	1.20	7	6	HS	HS	8150	
9/28/66	608-01	3.5	30	200	+11	150	+120	1.20	7	6	HS	HS	8150	
"	608-02	3	30	200	+11	130	+100	1.20	7	6	HS	HS	8150	
"	608-03	3	30	200	+11	150	+120	1.20	7	6	HS	150	8150	
"	608-04	3.5	40	200	+11	170	-130	1.20	7	6	HS	150	8150	
"	608-05	3.5	30	200	+11.5	30	0	1.20	7	6	HS	HS	8150	
"	608-06	3	30	200	+11.5	150	-120	1.20	7	6	HS	150	8150	

LIST OF SERIES 600 TESTS, FIRST SERIES - GRID A

DATE	SEQUENCE	WEATHER CONDITIONS				UNDERGROUND BLOWER UNIT					ORIENTATION OF ABOVE-GRND. ENGINES		ENGINE OPERATIONAL SPEED	NOTES
		WIND		VISIBILITY (m)	TEMP. °C	GRID ORIENTATION	δ	DILUTION RATE	DIRECTIONAL PLATES					
		SPEED (m/s)	DIR.						TYPE	α(°)	3	5		
9/28/66	608-07	3.5	40	200	+11.5	150	-110	1.20	7	6	150	150	8150	
"	608-08	3.5	50	200	+13	60	-10	1.20	7	6	HS	HS	5000/8150	
"	608-09	3.5	55	200	+13	105	-50	1.20	7	6	HS	150	8150	
"	608-10	3.5	50	200	+13	150	-100	1.20	7	6	150	150	8150	
11/12/66	609-01	2.5	110	100	+2	150	-40	1.20	7	6	HS	HS	8150	
"	609-02	3	120	100	+2	180	-60	1.20	7	6	HS	HS	8150	
"	609-03	3	120	100	+1.5	210	-90	1.20	7	6	HS	HS	8150	
"	609-04	3.5	95	100	+1.5	225	-130	1.20	7	6	HS	HS	8150	
"	609-05	2	100	100	+1.5	120	-20	1.20	7	6	HS	HS	8150	
"	609-06	3	120	125	+2	90	+30	1.20	7	6	HS	HS	8150	
11/25/66	610-01	2	210	150	-0.5	150	+60	1.20	7	6	150	150	8150	
12/8/66	611-01	4.5	190	175	+5.5	150	+40	1.20	7	6	150	150	8150	T
12/26/66	612-01	0.5	210	150	-4.5	120	+90	1.20	7	6	120	120	8150	

LIST OF SERIES 600 TESTS, SECOND SERIES, GRID B

DATE	SEQUENCE	WEATHER CONDITIONS				UNDERGROUND BLOWER UNIT					ORIENTATION OF ABOVE-GRND. ENGINES		ENGINE OPERATIONAL SPEED	NOTES
		WIND		VISIBILITY (m)	TEMP. °C	GRID ORIENTATION	δ	DILUTION RATE	DIRECTIONAL PLATES					
		SPEED (m/s)	DIR.						TYPE	α (°)	3	5		
9/28/67	631-01	2	130	100	+16	150	-20	1.20	8	6	HS	HS	8150	
"	631-02	1.5	130	100	+16	200	-70	1.20	8	6	HS	HS	8150	
"	631-03	1	135	100	+16	105	+30	1.20	8	6	HS	HS	8150	
"	631-04	1	135	100	+16	105	+30	1.20	8	6	HS	HS	8150	
"	631-05	0.5	130	100	+16	90	+40	1.20	8	6	HS	HS	8150	
"	631-06	1	130	100	+16	210	-80	1.20	8	6	HS	HS	8150	
9/29/67	632-01	2.5	170	150	+17	180	-10	1.20	8	6	HS	HS	8150	T
"	632-02	2.5	180	170	+17	180	0	1.20	8	6	HS	HS	8150	T (ND)
"	632-03	2	150	170	+19	90	+60	1.20	8	6	HS	HS	8150	T (ND)
"	632-04	2.5	155	170	+19	75	+80	1.20	8	6	HS	HS	8150	T
10/10/67	633-01	2	150	150	+11.5	120	+30	1.20	8	6	120	120	8150	T (ND)
"	633-02	2.5	160	150	+13.5	120	+40	1.20	8	6	HS	HS	8150	T
"	633-03	3	160	200	+14	80	+80	1.20	8	6	HS	HS	8150	T (ND)
11/13/67	634-01	2.5	170	200	+6	120	+50	1.20	8	6	HS	HS	8150	T
"	634-02	1.5	175	200	+7	85	+90	1.20	8	6	HS	HS	8150	T
"	634-03	1	180	200	+7	120	+60	1.20	8	6	120	120	8150	
12/4/67	635-01	2	270	400	+2.5	120	+150	1.20	8	6	HS	HS	8150	T (ND)
"	635-02	2	240	400	+3	120	+120	1.20	8	6	120	HS	8150	T (ND)
"	635-03	3	220	100	+4	120	+100	1.20	8	6	120	120	8150	T (ND)
"	635-04	3.5	230	100	+5	120	+110	1.20	8	6	HS	HS	8150	T
12/14/67	636-01	1.5	0	55	+6	120	-120	1.20	8	6	120	120	8150	T
"	636-02	1.5	20	55	+7	150	-130	1.20	8	6	HS	HS	8150	T
"	636-03	1.5	10	110	+7	180	-170	1.20	8	6	HS	HS	8150	T
"	636-04	1	20	170	+7	120	-100	1.20	8	6	HS	HS	8150	A
10/6/69	637-01	1.5	160	200	+12	150	+10	1.20	8	6	HS	HS	8100	
"	637-02	2	180	300	+13.5	150	+30	1.20	8	6	HS	HS	8100	
10/11/69	638-01	3.5	20	200	+11	180	-160	1.20	8	6	HS	HS	8100	
"	638-02	3.5	30	200	+11	150	-120	1.20	8	6	HS	HS	8100	
"	638-03	3	20	250	+11	120	-100	1.20	8	6	HS	HS	8100	
"	638-04	3	20	350	+11	120	-100	1.20	8	6	HS	HS	3000	A

LIST OF SERIES 600, TESTS, SECOND SERIES - GRID B

DATE	SEQUENCE	WEATHER CONDITIONS				UNDERGROUND BLOWER UNIT					ORIENTATION OF ABOVE-GRND. ENGINES		ENGINE OPERATIONAL SPEED	NOTES
		WIND		VISIBILITY (m)	TEMP. °C	GRID ORIENTATION	δ	DILUTION RATE	DIRECTIONAL PLATES					
		SPEED (m/s)	DIR.						TYPE	α (°)	3	5		
10/15/69	639-01	0.5	250	<50	+7	150	+100	1.20	8	6	HS	HS	8100	
"	639-02	0		<50	+7	120		1.20	8	6	HS	HS	8100	
"	639-03	0		<50	+7	180		1.20	8	6	HS	HS	8100	
"	639-04	0		<50	+7	165		1.20	8	6	HS	HS	8100	
"	639-05	0		<50	+7	90		1.20	8	6	HS	HS	8100	
"	639-06	0		100	+7	75		1.20	8	6	HS	HS	8100	
"	639-07	0		200	+9	150		1.20	8	6	HS	HS	8100	
10/16/69	640-01	0		100	+6	150		1.20	8	6	HS	HS	8100	
"	640-02	0.5	135	100	+6	105	+30	1.20	8	6	HS	HS	8100	
"	640-03	0.5	135	100	+6	195	-60	1.20	8	6	HS	HS	8100	
"	640-04	1	130	200	+6.5	180	-50	1.20	8	6	HS	HS	8100	A
10/18/69	641-01	0.5	110	100	+5	150	-40	1.20	8	6	HS	HS	8100	
"	641-02	1	95	100	+5	195	-100	1.20	8	6	HS	HS	8100	
"	641-03	1	100	100	+5	180	-80	1.20	8	6	HS	HS	8100	
"	641-04	1.5	110	150	+6	120	-10	1.20	8	6	HS	HS	8100	
"	641-05	1.5	125	150	+6	105	+20	1.20	8	6	HS	HS	8100	
"	641-06	1.5	100	150	+6	180/120	+80/+20	1.20	8	6	HS	HS	8100	
"	641-07	1.5	120	200	+7	150	-30	1.20	8	6	HS	HS	3000	A
10/21/69	642-01	0		100	+8	180/120		1.20	8	6	HS	HS	8100	
"	642-02	0		100	+8	190/110		1.20	8	6	HS	HS	8100	
"	642-03	0.5	255	150	+8	195/105	+60/+150	1.20	8	6	HS	HS	8100	