ETSO-C117b

ED Decision 2020/011/R (applicable from 25.7.2020)

AIRBORNE WIND SHEAR WARNING AND ESCAPE GUIDANCE SYSTEMS (REACTIVE TYPE) FOR TRANSPORT AEROPLANES

1 Applicability

This ETSO provides the requirements that airborne wind shear warning and escape guidance systems (reactive type) for transport aeroplanes that are designed and manufactured on or after the date of this ETSO, must meet in order to be identified with the applicable ETSO marking. It is not applicable to systems that look ahead to sense wind shear conditions before the phenomenon is encountered, nor to systems that use atmospheric and/or other data to predict the likelihood of a wind shear alert.

Appendix 1 to this ETSO describes the MPS for the airborne wind shear warning and escape guidance systems for transport category aeroplanes.

Appendix 2 to this ETSO describes the wind field models used to evaluate the performance of a wind shear warning and escape guidance system.

Appendix 3 to this ETSO describes the conversion of the velocity equations in Appendix 2 to rectangular coordinates.

Appendix 4 to this ETSO contains data that defines the Dryden turbulence model and the discrete gust model used in conducting the required wind shear alert tests.

Appendix 5 to this ETSO describes shear intensity.

Appendix 6 to this ETSO provides a sample computer listing for a simplified aeroplane simulation model for evaluating the effectiveness of various guidance schemes.

2 Procedures

2.1 General

The applicable procedures are detailed in CS-ETSO, Subpart A.

2.2 Specific

None.

3 Technical Conditions

3.1- General

3.1.1 Minimum Performance Standard

The applicable standards are provided in the attached Appendix 1.

3.1.2 Environmental Standard

See CS-ETSO, Subpart A, paragraph 2.1

3.1.3 Computer Software

See CS-ETSO, Subpart A, paragraph 2.2.

3.1.4 Airborne Electronic Hardware

See CS-ETSO, Subpart A, paragraph 2.3.

3.2 Specific

3.2.1 Failure Condition Classification

See CS-ETSO, Subpart A, paragraph 2.4.

A failure of the function defined in 3.1.1 above that results in an unannunciated malfunction or a missed wind shear detection is a major failure condition.

A loss of the function defined in 3.1.1 above is a minor failure condition.

4 Marking

4.1 General

See CS-ETSO, Subpart A, paragraph 1.2.

4.2 Specific

None.

5 Availability of Referenced Documents

See CS-ETSO, Subpart A, paragraph 3.

[Amdt ETSO/16]

Appendix 1 to ETSO-C117b – EASA Performance Standard for Airborne Wind Shear Warning and Escape Guidance Systems for Transport Aeroplanes

ED Decision 2020/011/R

1. PURPOSE

This Appendix establishes the minimum performance standard (MPS) for airborne wind shear warning and escape guidance systems for transport category aeroplanes.

2. SCOPE

The scope of this Appendix is to provide MPS for airborne wind shear warning and escape guidance systems for transport category aeroplanes. All the paragraph references cited herein are in reference to this Appendix only.

This performance standard applies only to wind shear warning systems which identify wind shear phenomena by sensing an encounter with conditions that exceed the threshold values contained in this performance standard. In addition to wind shear warning criteria, this performance standard provides criteria that are applicable to systems that provide optional wind shear caution alert capabilities. Wind shear escape guidance is provided to assist the pilot in obtaining the desired flight path during such an encounter.

3. DEFINITION OF TERMS

a. Airborne wind shear warning system

A device or system which uses various sensor inputs to identify the presence of wind shear once the phenomenon is encountered, and provides the pilot with a timely warning. The system may include both wind shear warning and wind shear caution alerts. A warning device of this type does not provide escape guidance information to the pilot to satisfy the criteria for warning and flight guidance systems.

b. Airborne wind shear warning and escape guidance system

A device or system which uses various sensor inputs to identify the presence of wind shear once the phenomenon is encountered, and provides the pilot with a timely warning and adequate flight guidance to improve the probability of recovery from the wind shear encounter. This system may include both wind shear warning and wind shear caution alerts.

c. Airborne wind shear auto recovery system

A device or system which integrates or couples autopilot and/or autothrottle systems of the aeroplanes with an airborne wind shear flight guidance system.

d. Airborne wind shear escape guidance system

A system which provides the crew with flight guidance information to improve the probability of recovery once a wind shear phenomenon is encountered.

e. Failure

The inability of a system, subsystem, unit, or part to perform within the previously specified limits.

f. False warning or caution

A warning or caution which occurs when the wind shear warning or caution threshold of the system is not exceeded.

g. Nuisance warning or caution

A warning or caution which occurs when a phenomenon is encountered, such as turbulence, which does not, in fact, endanger the aeroplane because of the duration of the subsequent change in the magnitude of the wind shear.

h. Recovery procedure

A vertical flight path control technique that is used to maximise the potential for a recovery from an inadvertent encounter with wind shear.

i. Severe wind shear

A wind shear of sufficient intensity and duration that it exceeds the performance capability of a particular aeroplane type. This would be likely to cause an inadvertent loss of control or ground contact if the pilot did not have information available from an airborne wind shear warning and escape guidance system which meets the criteria of this ETSO.

j. Wind shear caution alert

An alert that is triggered by increasing performance conditions, which is set at a wind shear level that requires immediate crew awareness and probably subsequent corrective action by the pilot.

k. Wind shear warning alert

An alert that is triggered by decreasing performance conditions, which is set at a wind shear level that requires immediate corrective action by the pilot.

4. GENERAL REQUIREMENTS

In addition to the performance requirements provided in the main text of this Performance Standard and in the Appendices to ETSO-C117b, the following general requirements and equipment characteristics are defined below:

a. General standards

The following general requirements shall be met by all wind shear warning and escape guidance systems:

(1) Airworthiness

The design and manufacture of the airborne equipment shall provide for installation so as not to impair the airworthiness of the aeroplane The material shall be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aeroplane systems. The workmanship shall be consistent with high-quality aeroplane electromechanical and electronic component manufacturing practices.

(2) General performance

The equipment shall perform its intended function, as defined by the manufacturer.

(3) Fire resistance

Except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not significantly contribute to the propagation of fire, all the materials that are used shall be self-extinguishing. One means to show compliance with this requirement is contained in Part 25, Appendix F.

(4) Operation of controls

Controls that are intended for use during flight shall be designed to minimise errors, and when operated in any possible combinations and sequences, shall not result in a condition whose presence or continuation would be detrimental to the continued performance of the equipment.

(5) Accessibility of controls

Controls that are not normally adjusted in flight shall not be readily accessible to the operator.

(6) Interfaces

The interfaces with other aeroplane equipment shall be designed such that the normal or abnormal operation of the wind shear warning and escape guidance equipment does not adversely affect the operation of other equipment.

(7) Compatibility of components

If a system component is individually acceptable but requires calibration adjustments or matching to other components in the aeroplane for its proper operation, it shall be identified in a manner that will ensure its performance to the requirements specified in this ETSO.

(8) Interchangeability

System components which are identified with the same manufactured part number shall be completely interchangeable.

(9) Control/display capability

A suitable interface shall be provided to allow data input, data output, and control of the operation of the equipment. The control/display shall be operable by one person with the use of only one hand.

(10) Control/display readability

The equipment shall be designed so that all the displays and controls are readable under all cockpit ambient light conditions, ranging from total darkness to reflected sunlight, and are arranged to facilitate the use of the equipment. If limitations are necessary on equipment installations to ensure that the displays are readable, they shall be included in the installation instructions.

(11) Effects of test procedures

The design of the equipment shall be such that the application of the specified test procedures does not produce a condition that is detrimental to the performance of the equipment, except as specifically allowed.

(12) Equipment computational response time

The equipment shall employ suitable update rates for the computation and display of detection and guidance information.

(13) Supplemental heating or cooling

If supplemental heating or cooling is required by system components to ensure that the requirements of this ETSO are met, they shall be specified by the equipment manufacturer in the installation instructions.

(14) Self-test capability

The equipment shall employ a self-test capability to verify the proper operation of the system.

(i) Any manually initiated self-test mode of operation shall automatically return the system to the normal operating mode upon completion of a successful test.

(ii) Any automatically activated self-test feature shall annunciate this mode of operation to the pilot if this feature activates annunciation lights, aural messages, or displaces the guidance commands in any way.

(iii) Use of the system self-test feature shall not adversely affect the performance of operation of other aeroplane systems.

(iv) A failure of the system to successfully pass the self-test shall be annunciated.

(15) Independence of warning and escape guidance functions

Irrespective of whether the warning and escape guidance functions are in a combined system or are separate systems, they should be sufficiently independent such that a failure of either system does not necessarily preclude or inhibit the presentation of information from the other. A warning system failure shall not result in any ambiguous or erroneous guidance system mode annunciations.

(16) System reliability

(i) The probability of a false warning being generated within the wind shear warning system or the wind shear warning and escape guidance system shall be 1E-4 or less per flight hour.

(ii) The probability of an unannunciated failure of the wind shear warning system or the wind shear warning and escape guidance system shall be 1E-5 or less per flight hour (reserved).

b. Equipment functional requirements — standard conditions

The equipment shall meet the following functional requirements:

(1) Mode annunciation

The mode of operation of the wind shear escape guidance display shall be annunciated to the pilot upon activation of the escape guidance during a wind shear encounter, and upon reversion to a different flight guidance mode.

(2) Malfunction/failure indications

The equipment shall indicate:

(i) any inadequacy or absence of primary power;

(ii) equipment failures;

(iii) inadequate or invalid warning or guidance displays or output signals; and

(iv) inadequate or invalid sensor signals or sources.

These malfunction/failure indications shall occur independently of any operator actions. The lack of adequate warning displays, escape guidance information, or sensor signals or sources shall be annunciated when compliance with the requirements of this ETSO cannot be assured.

(3) Wind shear caution alert

If the equipment includes a wind shear caution:

(i) it shall provide an annunciation of increasing performance shear (updraft, increasing headwind, or decreasing tailwind) in accordance with the shear intensity curve shown in Figure 1;

(ii) this caution alert shall display or provide an appropriate output for display of an amber caution annunciation dedicated for this purpose. An aural alert may be provided as an option. The caution display (or output) should remain until the threshold wind shear condition no longer exists (not less than 3 seconds) or a wind shear warning alert occurs; and

(iii) gust conditions shall not cause a nuisance caution alert. Turbulence shall not cause more than one nuisance caution alert per 250 hours (or 3 000 flight cycles based on 1 hour/flight cycle) of system operation.

(4) Wind shear warning alert

(i) A wind shear warning alert shall provide an annunciation of decreasing performance shear (downdraft, decreasing headwind, or increasing tailwind) with a magnitude that is greater than or equal to that shown in the shear intensity curve shown in Figure 1.

(ii) This warning alert shall display or provide an appropriate output for display of a red warning annunciation labelled 'wind shear' dedicated for this purpose. The visual alert should remain at least until the threshold wind shear condition no longer exists, or for a minimum of 3 seconds, whichever is greater. An aural alert shall be provided that annunciates 'wind shear' for 3 aural cycles. The aural alert need not be repeated for subsequent wind shear warning alerts within the same mode of operation.

(iii) Gust conditions shall not cause a nuisance warning alert. Turbulence shall not cause more than 1 nuisance warning alert per 250 hours (or 3 000 flight cycles based on 1 hour/flight) of system operation.

(5) Wind shear alert with increased approach sensitivity and reduced take-off sensitivity modes

(i) Increased approach sensitivity mode. If the system separates the approach and take-off scenarios, the crew may reduce the shear intensity level in the approach mode to increase the probability of providing timely wind shear alerts. They may lower the floor of the shear intensity curve 'must alert' curve in Figure 1 from 0.105 to 0.090. If they lower the floor, they may also modify the turbulence rejection tests in paragraph 4(d)(7)(ii) such that an alert in this region is not a failure of the turbulence rejection test.

(ii) Reduced take-off sensitivity mode. If the system separates the approach and take-off scenarios, the crew may desensitise the take-off mode to reduce the probability of unwanted alerts. They may raise the floor of the shear intensity 'must alert' curve in Figure 1 from 0.105 to 0.120.

(iii) Additional reduced take-off sensitivity mode. Some high-performance jet aeroplanes receive unwanted wind shear alerts after take-off when climbing at high rates through atmospheric wind gradients. If these unwanted alerts risk desensitising pilots to wind shear alerting, the crew may tailor the floor of the shear intensity 'must alert' curve in Figure 1 to reduce these unwanted alerts under the following conditions:

(a) The airborne wind shear warning and escape guidance system can determine that the aeroplane is in the take-off versus approach phase.

(b) The aeroplane is climbing at a high rate of climb, the aeroplane continues to climb at a high rate, and the rate of climb is known to create unwanted wind shear alerts.

(c) The aeroplane power setting is at or near a level that is representative of the maximum for the segment of the take-off; for example, maximum take-off thrust.

(d) The Figure 1 shear intensity 'must alert' curve shall be complied with after take-off.

(6) Alerting prioritisation

If alerting is prioritised in the presentation for a wind shear warning and escape guidance system (reactive wind shear), forward-looking wind shear system, terrain awareness and warning system, ground proximity warning system, traffic collision avoidance system, or when a simultaneous aural annunciation could occur, sequencing shall be implemented that ensures that reactive wind shear warning alerts are presented or annunciated first. Reactive wind shear alerts that are cautions have a lower priority than all terrain awareness and warning or ground proximity warning system alerts.

(7) The reactive wind shear systems caution alert should be disabled if a forward-looking wind shear system is in operation. It is acceptable to issue reactive wind shear caution alerts if the forward-looking wind shear system is inoperative.

(8) Operating altitude range

The system shall be designed to function from at least 50 feet above ground level (AGL) to at least 1 000 feet AGL.

(9) Wind shear escape guidance

Flight guidance algorithms shall incorporate the following design considerations:

(i) At the point of the system warning threshold, the available energy of the aeroplane shall be properly managed through a representative number of wind field conditions. These conditions shall take into account significant shear components in both the horizontal and vertical axes, individually and in combination.

(ii) The flight path guidance commands shall be suitable for the dynamic response of aeroplane of the type on which the system is intended for installation. The applicant shall demonstrate that the flight guidance commands during a dynamic wind shear encounter can be followed without resulting in pilot-induced oscillations.

(iii) If the magnitude of the shear components is such as to overcome the performance capability of the aeroplane, guidance commands shall be such that a ground impact will occur in the absence of the ability to produce additional lift, an absence of excessive kinetic energy, and without putting the aeroplane into a stalled condition.

(iv) Flight guidance command information shall be provided for presentation on the primary flight display/attitude direction indicator (PFD/ADI) and any available head-up display (HUD).

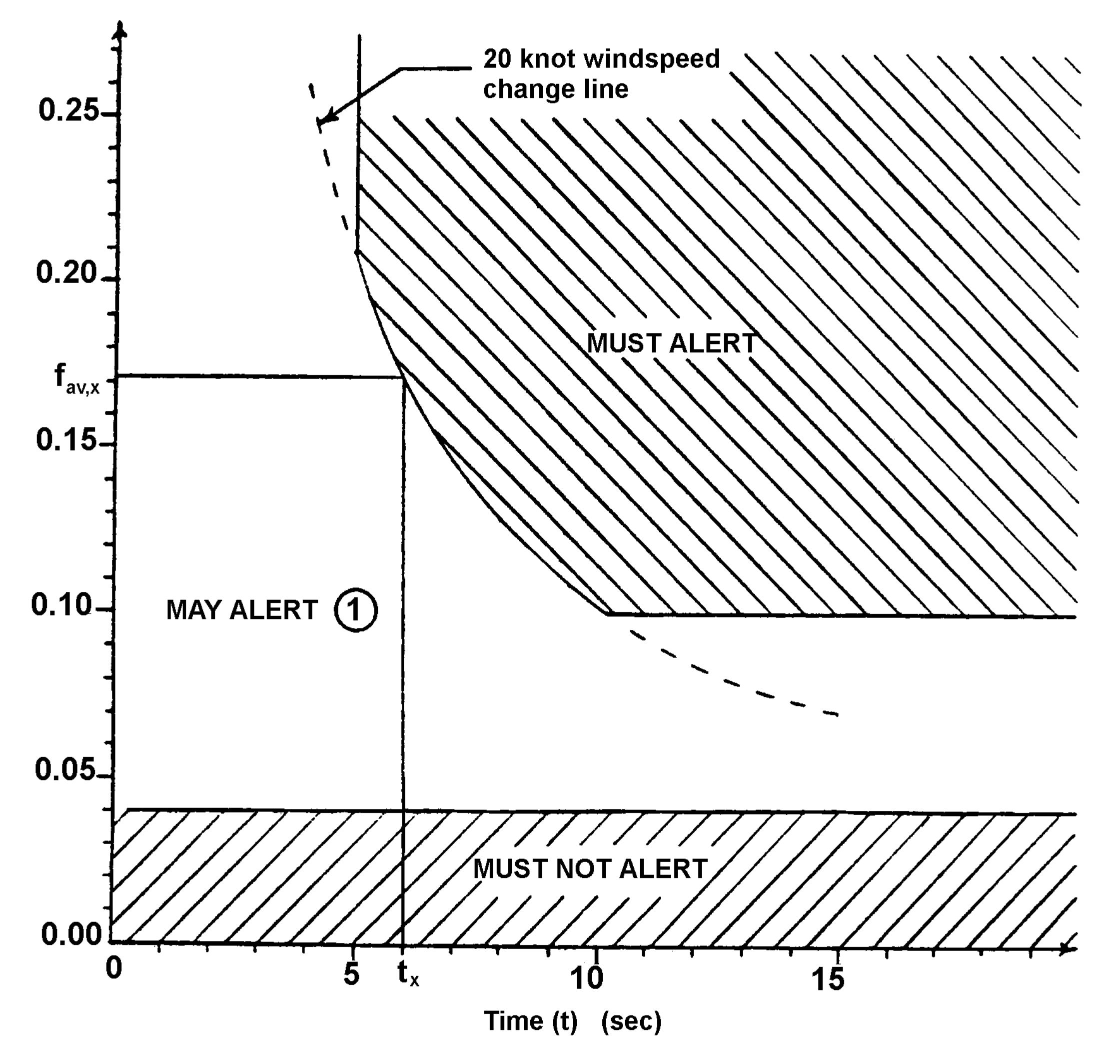
(v) Flight guidance displays which command the flight path and pitch attitude should be limited to an angle of attack that is equivalent to the onset of a stall warning or a maximum pitch command of 27°, whichever is less.

(vi) Flight guidance commands and any auto recovery mode (if included) may be automatically activated concurrently with or after the wind shear warning alert occurs, or may be manually selected. If manual selection is utilised, it shall only be via the take-off/go-around (TOGA) switch or equivalent means (i.e. a function of the throttle position, other engine parameters, etc.).

(vii) Manual deselection of wind shear flight guidance and any auto recovery mode (if included) shall be possible by means other than the TOGA switches.

(viii) Systems that incorporate the automatic reversion of flight guidance commands from wind shear escape guidance to another flight guidance mode should provide a smooth transition between the modes. Flight guidance commands shall not be removed from the flight guidance display until either they are manually deselected or until the aeroplane, following the end of the warning conditions, has maintained a positive rate of climb and speed above 1.3 Vs1 for at least 30 seconds.

FIGURE 1 — SHEAR INTENSITY CURVE



$f_{av,x}$ = average shear intensity to cause a warning at time t_x (resulting in a 20-knot wind speed change, bounded as shown; applies to horizontal, vertical, and combination shear intensities),

$$= \frac{\int_0^{t_x} f(t)dt}{t_x},$$

whereby f(t) = instantaneous shear intensity at time t.

1 A nuisance warning test that utilises the Dryden turbulence model and discrete gust model is conducted independently from the alert threshold tests to verify the acceptability of potential nuisance warnings due to turbulence or gusts.

c. Equipment performance — environmental conditions

(1) The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means to determine the overall performance characteristics of the equipment under conditions that are representative of those that may be encountered in actual operations. Table 1 defines the environmental tests that are required for the equipment. It shows the section numbers in ED-14G that describe the individual environmental tests. Some of the environmental tests contained in this subsection do not need to be performed unless the manufacturer wishes to qualify the equipment for that particular environmental condition. These tests are identified by the phrase 'When required' in Table 1. If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these 'When required' tests shall be performed.

(2) Environmental requirements. The following subset of performance requirements shall be met under the environmental conditions required by paragraph 3.1.2 of this ETSO. Additionally, all the system controls, displays, inputs and outputs shall perform their intended functions when subjected to the ED-14G environmental conditions.

(i) Section 4.b(1) — Mode Annunciation

(ii) Section 4.b(2) — Malfunction/Failure Indications

(iii) Section 4.b(3) — Wind Shear Caution Alert, except paragraph 4.b(3)(iii)

(iv) Section 4.b(4) — Wind Shear Warning Alert, except paragraph 4.b(4)(iii)

(v) Section 4.b(5) — Wind Shear Alert with Increased Approach Sensitivity and Reduced Take-off Sensitivity Modes

(vi) Section 4.b(9) — Wind Shear Escape Guidance

(3) The applicant shall conduct environmental qualification tests for the following shear intensity ($f_{av,x}$) and exposure time (s) in Figure 1: 0.1050, 10; 0.1748, 6; and 0.2100, 5; and ensure that the system generates and displays alerts when required. A single representative wind shear waveform may be used for all the environmental tests if the system design is such that different waveforms will not affect the performance under environmental conditions. Gust and turbulence rejection tests are not required under environmental conditions.

Table 1 — Required EUROCAE ED-14G Testing by Category

Environmental Test	ED-14G Section	Required Test
Temperature and Altitude	4	
Ground Survival Low Temperature and Short-Time Operating Low Temperature		√
Low Operating Temperature		√

Ground Survival High Temperature and Short-Time Operating High Temperature		√
High Operating Temperature		√
In-Flight Loss of Cooling		When required
Altitude		√
Decompression		When required
Overpressure		When required
Temperature Variation	5	√
Humidity	6	√
Operational Shocks and Crash Safety	7	
Operational Shocks		√
Crash Safety		√
Vibration	8	√
Explosion Proofness	9	When required
Waterproofness	10	
Condensing Water Proof		When required
Drip Proof		When required
Spray Proof		When required
Continuous Stream Proof		When required
Fluids Susceptibility	11	
Spray		When required
Immersion		When required
Sand and Dust	12	When required
Fungus Resistance	13	When required
Salt Spray	14	When required
Magnetic Effect	15	√
Power Input	16	
Normal Operating Conditions (AC/DC)		√
Abnormal Operating Conditions (AC/DC)		√
Load Equipment Influence on Aeroplane Electrical Power System (AC/DC)		When required
Voltage spike	17	
Category A Requirements (If applicable)		√
Category B Requirements (If applicable)		√
Audio frequency conducted susceptibility	18	√

Induced Signal Susceptibility	19	√
RF Susceptibility	20	√
Emission of RF Energy	21	√
Lightning-induced Transient Susceptibility	22	√
Lightning Direct Effects	23	When required
Icing	24	When required
Electrostatic Discharge	25	When required
Fire, Flammability	26	√

d. Equipment test procedures

(1) Definitions of terms and conditions of tests. The following definitions of terms and conditions of tests are applicable to the equipment tests specified herein:

(i) Power input voltage. Unless otherwise specified, all the tests shall be conducted with the power input voltage adjusted to the design voltage ± 2 per cent. The input voltage shall be measured at the input terminals of the equipment under test.

(ii) Power input frequency

(a) In the case of equipment that is designed for operation from an AC power source of essentially constant frequency (e.g. 400 Hz), the input frequency shall be adjusted to the design frequency ± 2 per cent.

(b) In the case of equipment designed for operation from an AC power source of variable frequency (e.g. 300 to 1 000 Hz), unless otherwise specified, the test shall be conducted with the input frequency adjusted to within 5 % of a selected frequency and within the range for which the equipment is designed.

(iii) Wind field models. Unless otherwise specified, the wind field models used for the tests shall be those specified in Appendix 2 to ETSO-C117b.

(iv) Adjustment of equipment. The circuits of the equipment under test shall be aligned and adjusted in accordance with the manufacturer's recommended practices prior to the application of the specified tests.

(v) Test instrument precautions. Due precautions shall be taken during the execution of the tests to prevent the introduction of errors that result from the connection of voltmeters, oscilloscopes, and other test instruments across the input and output impedances of the equipment under test.

(vi) Ambient conditions. Unless otherwise specified, all the tests shall be made within the following ambient conditions:

— Temperature: + 15 to + 35 °C (+ 59 to + 95 °F)

— Relative humidity: Not greater than 85 %

— Ambient pressure: 84–107 kPa (equivalent to + 5 000 to – 1 500 ft) (+ 1 525 to – 460 m)

(vii) Warm-up period. Unless otherwise specified, all the tests shall be conducted after the manufacturer's specified warm-up period.

(viii) Connected loads. Unless otherwise specified, all the tests shall be performed with the equipment connected to loads which have the impedance values for which it is designed.

(2) Test procedures. The equipment shall be tested in all the modes of operation that allow different combinations of sensor inputs to show that it meets both the functional and accuracy criteria.

Dynamic testing provides quantitative data regarding the performance of wind shear warning and escape guidance equipment using a simplified simulation of flight conditions. This testing, when properly performed and documented, may serve to minimise the flight test requirements.

It shall be the responsibility of the equipment manufacturer to determine that the sensor inputs, when presented to the wind shear warning and escape guidance equipment, will produce performance that is commensurate with the requirements of this standard. Additional sensor inputs may be optionally provided to enhance the capability and/or performance of the equipment.

The equipment required to perform these tests shall be defined by the equipment manufacturer as a function of the specific sensor configuration of the equipment. Since these tests may be accomplished in more than one way, alternative test equipment set-ups may be used where equivalent test functions can be accomplished. Combinations of tests may be used wherever appropriate.

The signal sources of the test equipment shall provide the appropriate signal formats for input to the specific system under test without contributing to the error values that are being measured. Tests need only be performed once, unless it is otherwise indicated.

The scenarios that are established for testing wind shear warning and escape guidance systems represent realistic operating environments to properly evaluate such systems. The wind field models contained in Appendix 2 to ETSO C117b should be used to evaluate the performance of the wind shear warning and escape guidance systems. The manufacturer may propose different wind field models provided that it is shown that they represent conditions that are at least as severe as those contained in this ETSO.

– Note: The test waveform parameters provided in this ETSO are sufficiently broad to cover the wind field parameters that were observed in the known accident cases. However, the manufacturer is encouraged to verify that the detection systems will actually detect these wind shears by subjecting them to the wind field conditions specified for use in evaluating guidance commands.

(3) Test set-up. Simulator tests shall be used to demonstrate the performance capability of the wind shear warning and escape guidance equipment. A suitable equipment interface shall be provided for recording the relevant parameters that are necessary to evaluate the particular system under test. The aeroplane simulator shall be capable of appropriate dynamic modelling of a representative aeroplane and of the wind field and turbulence conditions contained in Appendices 2 and 3 to this ETSO, or other wind field/turbulence models that are found to be acceptable by the administrator.

Note: This section requires testing in a single representative aeroplane simulator. Approval of the installation will require system testing in an aeroplane simulator that is representative of the aeroplane. Thus, we recommend you to accomplish the paragraph 4(d)(3) simulator testing in as many representative simulators as are necessary to cover all the intended installations.

(4) Functional performance (paragraphs 4(b)(1) through 4(b)(5), 4(b)(8) and 4(b)(9)). Each of the functional capabilities identified in paragraphs 4(b)(1) through 4(b)(5), 4(b)(7) and 4(b)(8) shall be demonstrated with the wind shear warning and escape guidance equipment powered. These capabilities shall be evaluated either by inspection or in conjunction with the tests described in paragraphs 4(d)(5) through 4(d)(10).

(5) Mode annunciation (paragraph 4(b)(1)). With the equipment operating, verify that the wind shear escape guidance display mode of operation is annunciated to the pilot upon activation of the escape guidance and upon reversion to a different flight guidance mode.

(6) Malfunction/failure indications (paragraph 4(b)(2)). Configure the equipment for simulation tests as defined in paragraph 4(d)(3).

(i) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), remove one at a time each required electrical power input to the equipment. There shall be a failure indication by the equipment of each simulated failure condition.

(ii) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), cause each sensor or other signal input to become inadequate or invalid. There shall be a failure indication by the equipment of each simulated failure condition.

(7) Wind shear caution alert (paragraphs 4(b)(3) and 4(b)(5)(i)). For equipment that incorporates a wind shear caution alert function, accomplish the following tests:

(i) Configure the equipment for a simulation test as defined in paragraph 4(d)(3). Subject the equipment to acceleration waveform values that meet the following conditions (reference Figure 2). The system shall generate an appropriate caution alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (s)	Alert within (s) (3)
0.0200	20	no alert
0.0400	20	no alert
0.1050	10	10
0.1166	9	9
0.1311	8	8
0.1499	7	7
0.1748	6	6.2
0.2100	5	5.7
0.2700 (2)	5	5

Notes:

(1) The average shear intensity which shall result in a caution alert after a time t_x or less meets the definition of $f_{av,x}$ in Figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 % of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. The test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) In order to achieve the test condition with the shear intensity $f_{av,x}$ equal to or greater than 0.270, it is necessary to have an initial rise of sufficient rate to achieve a shear intensity f value that will allow subsequent rise and fall rates that are limited to 0.1 per second to achieve the required $f_{av,x}$ value.

(3) Account for latency due to the alert calculation and alert annunciation display functionality when measuring the alert time

The test conditions specified above shall be repeated 5 times for each axis (horizontal and vertical). A total of 90 runs are required for verification of the detection (9 conditions × 5 for each axis) for both performance increasing and performance decreasing wind shears. A different waveform for $f_{av,x}$ will be utilised for each of the 5 runs. An appropriate alert (or no alert) shall be generated for each test condition.

Verify that the system displays or provides an appropriate output for display of an amber caution annunciation that is dedicated for this purpose. Verify that the visual caution display (or output) remains at least until the threshold wind shear condition no longer exists, or a minimum of 3 seconds (whichever is greater), or until a wind shear warning occurs.

(ii) Subject the equipment to wind speeds that are defined by the Dryden turbulence model contained in Appendix 4 to ETSO C117b. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in Appendix 4 to ETSO C117b for a minimum total test duration of 250 hours (or 3 000 flight cycles based on 1 hour/flight cycle).

No more than 1 nuisance caution shall be generated during this test.

An alternative test equipment set-up may be used to accomplish the equivalent test function for the turbulence testing. A combination of analysis, simulation and testing may be used to demonstrate the performance of the equipment.

(iii) Subject the equipment to the wind speeds that are defined by the discrete gust rejection model contained in Appendix 4 to ETSO C-117b. No alert shall be generated as a result of this test.

(8) Wind shear warning alert (paragraphs 4(b)(4) and 4(b)(5)(ii)).

(i) Configure the equipment for simulation tests as defined in paragraph 4(d)(3). Subject the equipment to acceleration waveform values that meet the following conditions (reference Figure 2). The system shall generate an appropriate warning alert (or no alert) within the time intervals that are specified when it is subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (s)	Alert within (s) (3)
0.0200	20	no alert
0.0400	20	no alert
0.1050	10	10
0.1166	9	9
0.1311	8	8
0.1499	7	7
0.1748	6	6.6
0.2100	5	6.2
0.2700 (2)	5	5.7

Notes:

(1) The average shear intensity which shall result in a warning alert after a time t_x or less meets the definition of $f_{av,x}$ in Figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 % of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. The test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is

zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) In order to achieve the test condition with the shear intensity $f_{av,x}$ equal to or greater than 0.270, it is necessary to have an initial rise of a sufficient rate to achieve a shear intensity f value that will allow the subsequent rise and fall rates that are limited to 0.1 per second to achieve the required $f_{av,x}$ value.

(3) Account for any latency due to the alert calculation and alert annunciation display functionality when measuring the alert time.

The test conditions specified above shall be repeated 5 times for each axis (horizontal and vertical). A total of 90 runs are required for verification of the detection (9 conditions × 5 for each axis) for both performance increasing and performance decreasing wind shears. A different waveform for $f_{av,x}$ will be utilised for each of the 5 runs. An appropriate alert (or no alert) shall be generated for each test condition.

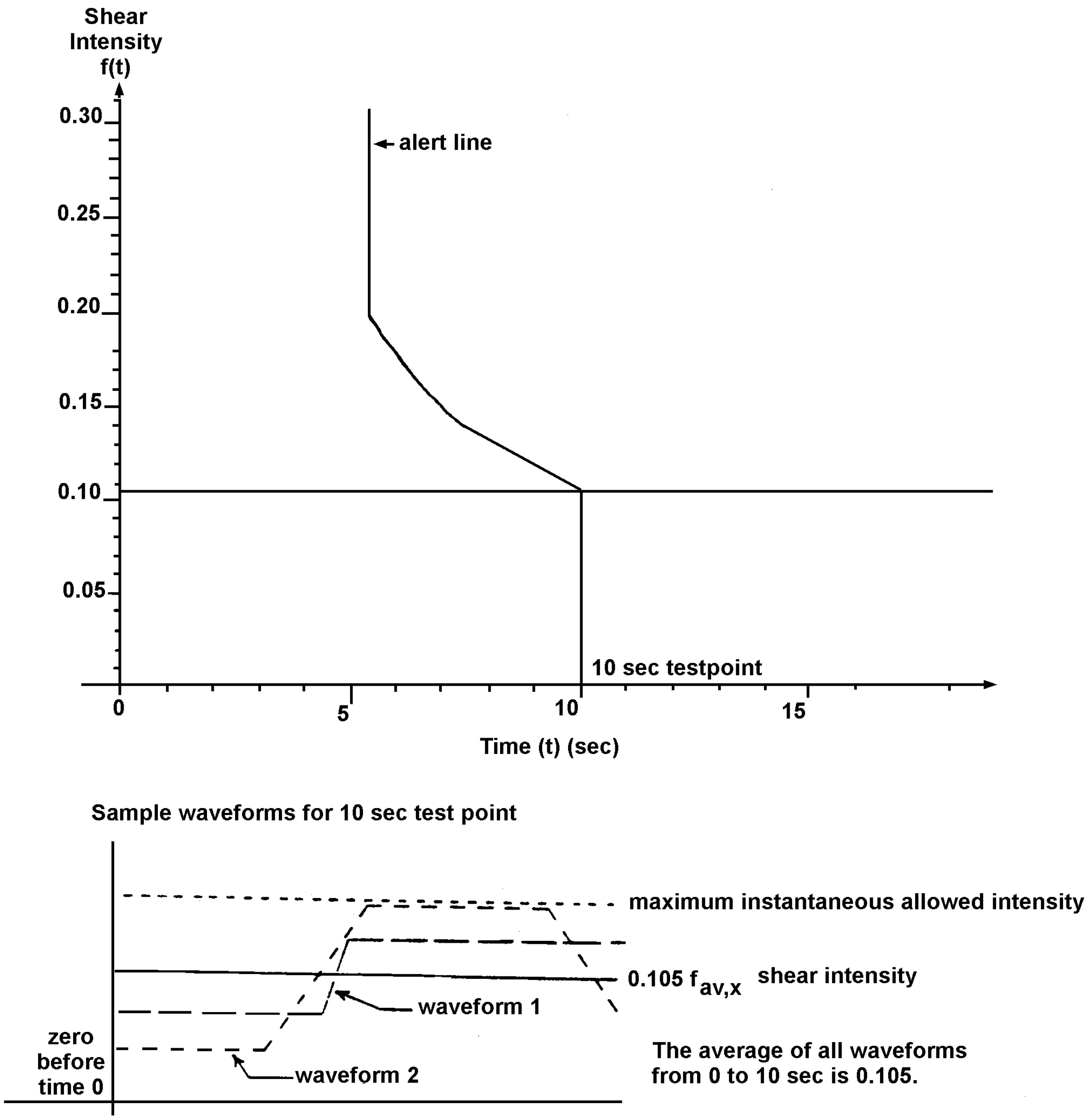
Verify that the system displays or provides an appropriate output for display of a red warning annunciation labelled 'wind shear' that is dedicated for this purpose. Verify that the visual warning display (or output) remains until the threshold wind shear condition no longer exists, or a minimum of 3 seconds, whichever is greater. Verify that an aural alert is provided that annunciates 'wind shear' for 3 aural cycles.

(ii) Subject the equipment to the wind speeds that are defined by the Dryden turbulence model contained in Appendix 4 to ETSO C117b. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in Appendix 4 to ETSO C117b for a minimum total test duration of 250 hours (or 3 000 flight cycles based on 1 hour/flight cycle). No more than 1 nuisance warning shall be generated during this test.

An alternative test equipment set-up may be used to accomplish the equivalent test function for the turbulence testing. A combination of analysis, simulation, and testing may be used to demonstrate the performance of the equipment specified in this paragraph 4(d)(8)(ii).

(iii) Subject the equipment to the wind speeds that are defined by the discrete gust rejection model contained in Appendix 4 to ETSO-C117b. No alerts shall be generated as a result of this test.

FIGURE 2 — WIND SHEAR ALERT TEST



(9) Operating altitude range (paragraph 4.b(8)). Configure the equipment for the simulation tests as defined in paragraph 4(d)(3). Simulate a take-off to an altitude of at least 1 500 feet AGL. Verify the wind shear warning and escape guidance system is operational from at least 50 feet AGL to at least 1 000 feet AGL. Simulate an approach to landing from 1 500 feet AGL to touchdown. Verify the wind shear warning and escape guidance system is operational from at least 1 000 feet AGL to at least 50 feet AGL.

(10) Wind shear escape guidance (paragraph 4.b(9)). Configure the equipment for simulation tests as defined in paragraph 4(d)(3). Subject the equipment to each of the wind field conditions contained in Appendix 2 to ETSO C117b for each operating mode (take-off, approach, landing, etc.) that is available. Each test condition shall be repeated 5 times. Recovery actions for the fixed pitch method comparison shall be initiated immediately upon entering the shear condition.

Notes:

(1) Evaluate wind shear escape guidance commands using a simulation that incorporates the necessary dynamic modelling of the representative aeroplane (more than 1 representative aeroplane model may be necessary) in which installation of the equipment is intended. Dynamic modelling of the representative aeroplane should include consideration of all the relevant effects, including but not limited to pitch and roll rates, control authority, delays between control inputs and aeroplane responses, display system leads and lags, etc.

(2) The simulator should provide for a pilot in the loop evaluation of guidance flyability during simulated wind shear encounters. The guidance command gains should be consistent with those incorporated in the flight guidance system. While 'fine-tuning' of the guidance commands to obtain the optimum performance for a specific aeroplane may be accomplished, the use of unique tailoring for a specific aeroplane may not be necessary. Evaluation through means of a suitable engineering simulation may be acceptable to demonstrate the suitability of the guidance commands for a representative aeroplane. However, the equipment manufacturer should demonstrate that the flight guidance commands during a dynamic wind shear encounter can be followed without resulting in pilot-induced oscillations.

(i) Verify that the flight path guidance commands manage the available energy of the aeroplane to achieve the desired trajectory through the shear encounter. These tests shall be performed with vertical only, horizontal only, and a combination of vertical and horizontal shear conditions. You may reduce the number of times you repeat each of these tests conditions to less than 5. To reduce the number of repetitions to less than 5, you shall have gathered sufficient data to demonstrate that the flight path guidance commands meet these requirements. You should also include aeroplane weight and centre of gravity variations if applicable.

a. For the take-off case, verify that the flight guidance commands produce a trajectory that provides a resultant flight path that is at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing a 15° pitch attitude (at an approximate rate of 1.5° per second) until the onset of a stall warning, and then reducing the pitch attitude to remain at the onset of a stall warning until the shear condition is exited. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path that is provided by the fixed pitch method that results from the use of the guidance commands provided by the system shall be adequately substantiated.

b. For the approach/landing case, verify that the flight guidance commands produce a trajectory that provides a resultant flight path that is at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing the maximum available thrust and a 15° pitch attitude (at an approximate rate of 1.5° per second) until the onset of stall warning, and then reducing the pitch attitude to remain at the onset of stall warning until the shear condition is exited. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path that is provided by the fixed pitch method that results from the use of the guidance commands that are provided by the system shall be adequately substantiated.

c. For shear conditions that exceed the available performance capability of the aeroplane, verify that the flight guidance commands result in a ground impact in the absence of the ability to produce additional lift, an absence of excessive kinetic energy, and without putting the aeroplane into a stalled condition.

Note: There is no requirement to perform the tests described in paragraphs 4(d)(10)(ii) through (vii) with horizontal only, vertical only, and a combination of vertical and horizontal shear conditions. You may perform the tests described in paragraphs 4(d)(10)(ii) through (vii) with only the combination vertical and horizontal shear conditions.

(ii) Verify that the flight guidance command outputs are capable of display on the associated flight displays. The interface specifications shall be verified and determined to be appropriate for the systems that are identified in the equipment installation instructions.

(iii) Verify that the pitch attitude commands do not result in an angle of attack that exceeds the onset of a stall warning or a maximum pitch command of 27°, whichever is less.

(iv) For systems that incorporate manual activation of recovery flight guidance commands, verify that the system is activated only by the TOGA switches (or equivalent means). For systems that provide automatic activation of recovery guidance, verify that the system is activated concurrently with the wind shear warning alert.

(v) Verify that the wind shear recovery guidance commands and any automatic recovery mode can be deselected by a means other than the TOGA switches.

(vi) For systems that incorporate automatic reversion of flight guidance commands from wind shear escape guidance to another flight guidance mode, verify that the transition between the flight guidance modes provides smooth guidance information.

Verify that flight guidance commands are not removed from the flight guidance display until either they are manually deselected or until the aeroplane, following the exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 Vs1 for at least 30 seconds.

[Amdt ETSO/16]

Appendix 2 to ETSO-C117b – Wind Field Models and Data

ED Decision 2020/011/R

This Appendix contains data that defines the wind field models to be used in conducting the tests specified in paragraph 4(d)(10) of this ETSO. This material was developed by the National Aeronautics And Space Administration (NASA), reference NASA Technical Memorandum 100632 [ref. 1].

The downburst model parameters below provide the variables to be used to obtain the representative test conditions: (1) and (2)

Radius of Downdraft (ft)	Maximum Outflow (ft/s)	Altitude of Max. Outflow (ft)	Distance from Starting Point (3) (ft)
920	37	98	20000 (-9000)
1180	47.6	98	15000 (-14000)
2070	58.4	131	25000 (-4000)
4430	68.9	164	30000 (1000)
9010	72.2	262	30000 (1000)
3450	88.2	197	25000 (-4000)
3180	53.1	262	30000 (1000)
1640	46	164	25000 (-4000)
5250	81.3	197	30000 (1000)
1250	67.6	100	25000 (-4000)

(1) From analytic microburst model documented in NASA TM-100632. These parameters are based on data from Proctor's Terminal Area Simulation System (TASS) model.

(2) For the takeoff case, the downburst centre is positioned at the point the aeroplane lifts off the runway for all test cases.

(3) For the approach/landing case, the downburst centre is positioned as stated. The test is begun with the aeroplane at an initial altitude of 1 500 feet on a 3° glideslope (touchdown point approximately 29 000 feet away). The distance from the starting point indicates where the centre of the downburst shaft is located relative to the starting point. The number in parentheses next to it indicates the relative distance of the microburst centre from the touchdown point (not the end of the runway). A negative number indicates that the microburst centre is located before the touchdown point, positive indicates it is past the touchdown point.

SUMMARY

A simple downburst model has been developed for use in batch and real-time piloted simulation studies of guidance strategies for terminal area transport aeroplane operations in wind shear conditions. The model represents an axisymmetric stagnation point flow, based on velocity profiles from the Terminal Area Simulation System (TASS) model developed by Proctor [ref. 3,4] and satisfies the mass continuity equation in cylindrical coordinates. Altitude dependence, including boundary layer effects near the ground, closely matches real-world measurements, as do the increase, peak, and decay of outflow and downflow with increasing distance from the downburst centre. Equations for horizontal and vertical winds were derived, and found to be infinitely differentiable, with no singular points existent in the flow field. In addition, a simple relationship exists among the ratio of maximum horizontal to vertical velocities, the downdraft radius, depth of outflow, and altitude of maximum outflow. In use, a microburst can be modelled by specifying four characteristic parameters. Velocity components in the x, y, and z directions, and the corresponding nine partial derivatives are obtained easily from the velocity equations.

INTRODUCTION

Terminal area operation of transport aircraft in a wind shear environment has been recognised as a serious problem. Studies of aeroplanes trajectories through downbursts show that specific guidance strategies are needed for aeroplanes to survive inadvertent downburst encounters. In order for guidance strategies to perform in simulations as in actual encounters, a realistic set of conditions must be present during development of the strategies. Thus, aeroplane and wind models that closely simulate real-world conditions are essential in obtaining useful information from the studies.

Wind models for use on personal computers, or for simulators with limited memory space availability, have been difficult to obtain because variability of downburst characteristics makes analytical models unrealistic, and large memory requirements make the use of numerical models impossible on any except very large capacity computers.

Bray [ref. 2] developed a method for analytic modelling of wind shear conditions in flight simulators, and applied his method in modelling a multiple downburst scenario from Joint Airport Weather Studies (JAWS) data. However, the altitude dependence of his model is not consistent with observed data and, although flexibility in sizing the downbursts is built into the model, it does not maintain the physical relationships which are seen in real-world data among the sizing parameters. In particular, boundary layer effects should cause the radial velocity to decay vertically to zero at the ground, as does the vertical velocity.

In a study conducted at NASA Langley Research Center, three different guidance strategies for a Boeing 737-100 aeroplane encountering a microburst on take-off were developed [ref. 3-4]. These strategies were first developed using a personal computer, and then implemented in a pilot-in-the-loop simulation using a very simple wind model in both efforts. The wind velocities used are depicted in Figure 1. This model consisted of a constant outflow outside of the downburst radius and a constant slope headwind to tailwind shear across the diameter of the downburst.

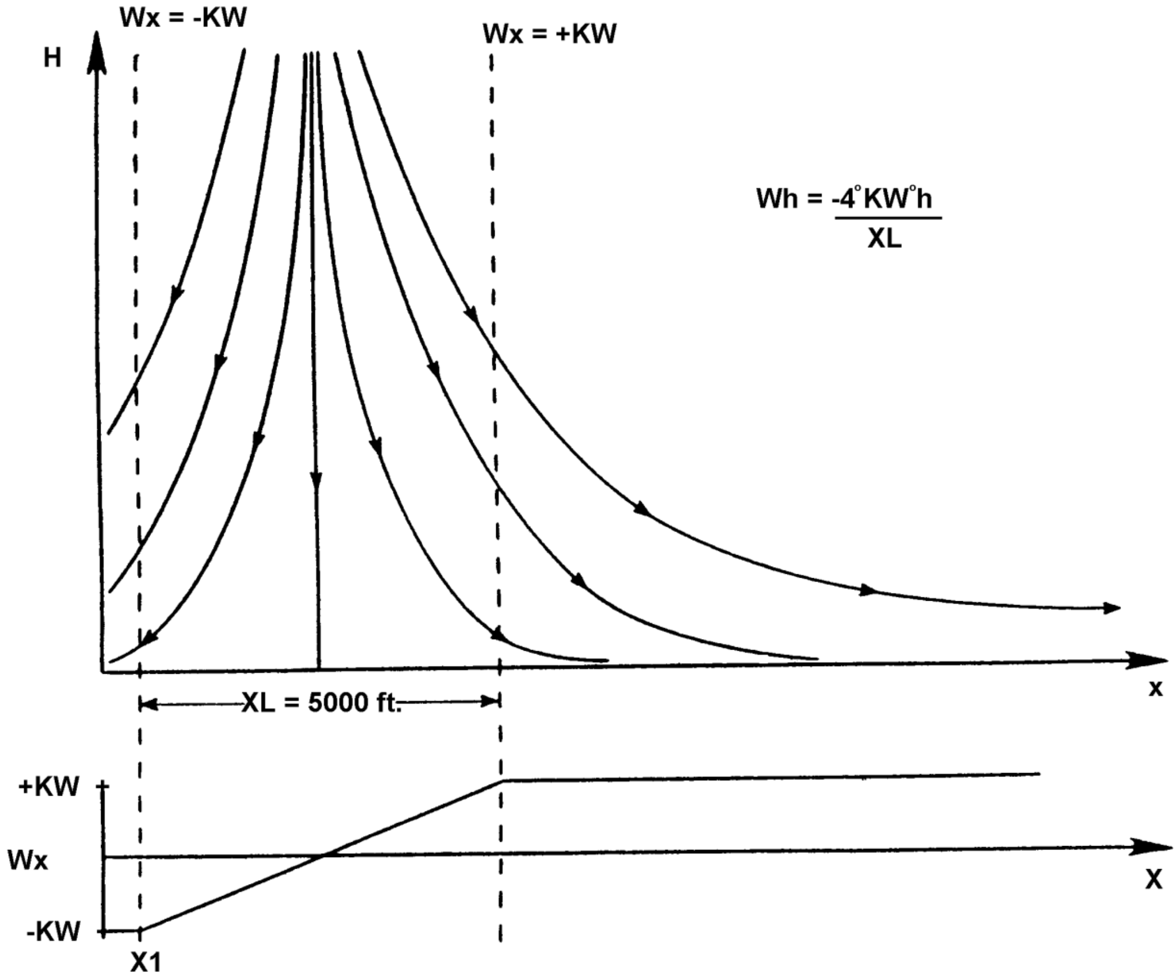


Figure 1 — Wind Model Used in Guidance Studies

It was recognised that a more realistic wind model could significantly alter the outcome of the trajectory. For the subsequent part of this study, which involves altering the aeroplane model to simulate approach to landing and escape manoeuvres and additional take-off cases, a more realistic wind model was preferred. The simple analytical model outlined in this report was developed for this purpose.

SYMBOLS

JAWS	Joint Airport Weather Studies
NIMROD	Northern Illinois Meteorological Research on Downbursts
R	radius of downburst shaft (ft)
r	radial coordinate (distance from downburst centre) (ft)

TASS	Terminal Area Simulation System
u	velocity in r-direction (or x-direction) (knots)
v	velocity in y-direction (knots)
w	velocity in z-direction (knots)
w_{max}	magnitude of maximum vertical velocity (knots)
u_{max}	magnitude of maximum horizontal velocity (knots)
x	horizontal (runway) distance, aeroplane to downburst centre (ft)
y	horizontal (side) distance, aeroplane to downburst centre (ft)
z	aeroplane altitude above ground level (ft)
z_h	depth of outflow (ft)
z_m	height of maximum U-velocity (ft)
z_{m2}	height of half-maximum U-velocity (ft)
z*	characteristic height, out of boundary layer (ft)
e	characteristic height, in boundary layer (ft)
λ	scaling factor (s-1)

DEVELOPMENT OF VELOCITY EQUATIONS

Beginning with the full set of Euler and mass continuity equations, some simplifying assumptions about the downburst flow conditions were made. Effects of viscosity were parameterised explicitly, and the flow was assumed to be invariant with time. The downburst is axisymmetric in cylindrical coordinates, and characterized by a stagnation point at the ground along the axis of the downflow column. The flow is incompressible, with no external forces or moments acting on it.

The resulting mass conservation equation is

$$\nabla \cdot v = 0. \qquad (1)$$

Written out in full, equation 2 is

$$\frac{\partial u}{\partial r} + \frac{\partial w}{\partial z} + \frac{u}{r} = 0. \qquad (2)$$

This equation is satisfied by solutions of the form

$$w = g(r^2)q(z) \qquad (3a)$$

$$u = \frac{f(r^2)}{r}p(z) \qquad (3b)$$

provided that

$$f'(r^2) = \frac{\lambda}{2}g(r^2) \qquad (4a)$$

$$q'(z) = \lambda p(z). \qquad (4b)$$

Note that $f'(r^2) = \frac{\partial f(r^2)}{\partial r^2}$. To solve this system of equations, solutions were assumed for two of the functions and the other two were obtained from equations 4a and 4b.

It was desired that the velocity profiles of this analytic model exhibit the altitude and radial dependence shown in the large-scale numerical TASS (Terminal Area Simulation System) weather model [ref. 6-9]. The TASS model is based on data from the Joint Airport Weather Studies (JAWS) [ref. 10], and provides a three- dimensional velocity field, frozen in time, for given locations of an aeroplane within the shear [ref. 11-12].

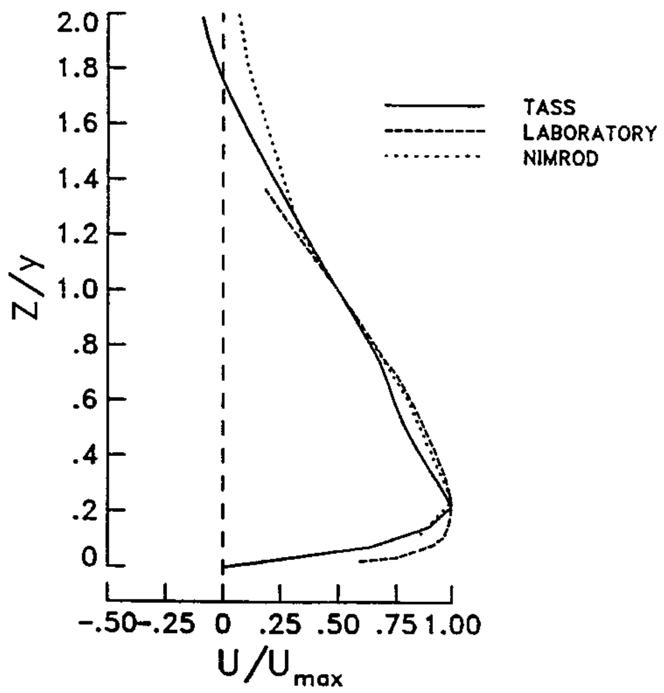


Figure 2 — Vertical Profile of Microburst Outflow (Non-dimensional)

Figure 2 shows dimensionless vertical profiles of horizontal velocity, u, for TASS data, laboratory data obtained by impingement of a jet on a flat plate, and data from NIMROD (Northern Illinois Meteorological Research on Downbursts) [ref. 13-21]. Specific points of interest are the maximum horizontal velocity (located 100-200 metres above the ground), below which is a decay region due to boundary layer effects, zero velocity at the stagnation point on the ground, and an exponential decay with altitude above the maximum velocity altitude. Vertical velocity profiles from TASS data are shown in Figure 3, also exhibiting a decay to zero at the stagnation point.

VERTICAL PROFILES OF VERTICAL VELOCITY FOR 30 JUN 82 CASE:
SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT

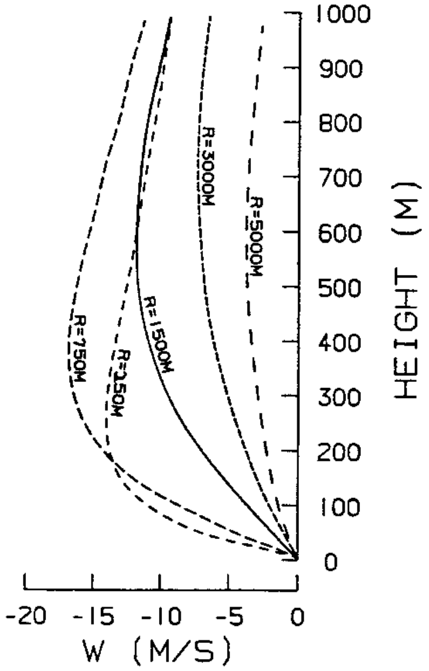


Figure 3 — Vertical Profile of Microburst Downflow

The radially varying characteristics desired for the horizontal wind were two peaks of equal magnitude and opposite direction located at a given radius, with a smooth, nearly linear transition between the two. Beyond the peaks, the velocity should show an exponential decay to zero. The vertical velocity was required to have a peak along the axis of symmetry (r = 0), and to decay exponentially as the radius increases.

A pair of shaping functions that gave velocity profiles matching the TASS data as required are given below.

$$g(r^2) = e^{-(r/R)^2}$$

$$p(z) = e^{-z/z^*} - e^{-z/\varepsilon}$$

The remaining solutions were found by integrating equations 4a and 4b, yielding:

$$f'(r^2) = \frac{\lambda R^2}{2}\left[1 - e^{-(r/R)^2}\right]$$

$$q(z) = -\lambda\{\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z * \left(e^{-z/z*} - 1\right)\}$$

Figures 4 and 5 show plots of these shaping functions.

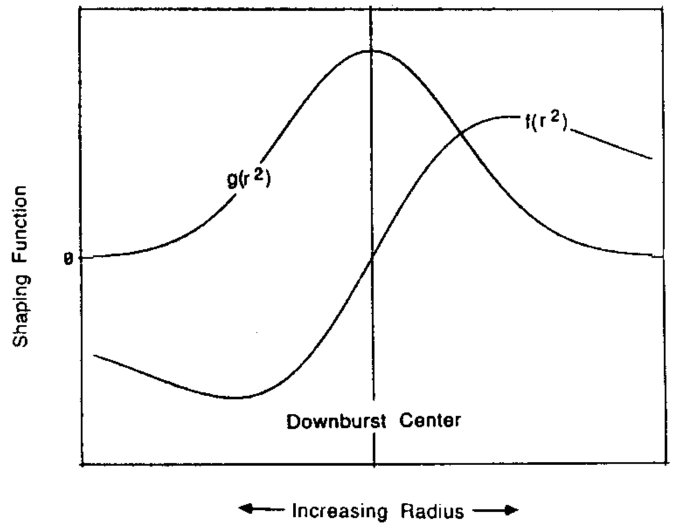


Figure 4 — Characteristic Variation of Horizontal Shaping Functions

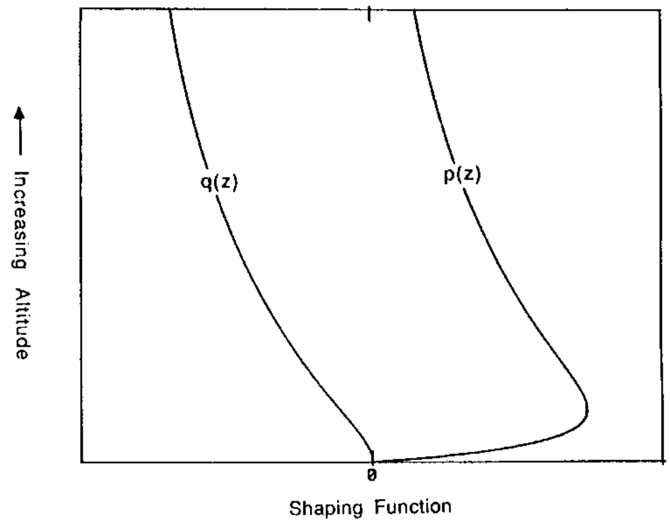


Figure 5 — Characteristic Variation of Vertical Shaping Functions

Combining the functions as in equation 3, the horizontal and vertical velocities are expressed as

$$u = \frac{\lambda R^2}{2r}\left[1 - e^{-(r/R)^2}\right]\left(e^{-z/z*} - e^{-z/\varepsilon}\right) \qquad (5)$$

$$w = -\lambda e^{-(r/R)^2}\left[\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z*\left(e^{-z/z*} - 1\right)\right] \qquad (6)$$

By taking derivatives of equations 5 and 6 with respect to r and z, respectively, and substituting in equation 2, it can be shown that the velocity distributions satisfy continuity.

The parameters z* and ε were defined as characteristic scale lengths associated with 'out of boundary layer' and 'in boundary layer' behaviour, respectively. Analysis of TASS data indicated that z* = z_{m2}, the altitude at which the magnitude of the horizontal velocity is half the maximum value.

It was also noted that the ratio

$$\frac{z_m}{z*} = 0.22$$

To determine the location of the maximum horizontal velocity, the partial derivatives of u with respect to r and z were set equal to zero. The resulting equation for the r-derivative is

$$2\left(\frac{r}{R}\right)^2 = e^{-(r/R)^2} - 1$$

The resulting equation for the z-derivative is

$$\frac{z_m}{z*} = \frac{1}{(z*/\varepsilon) - 1} \, 1n(z*/\varepsilon)$$

Recalling that $z_m/z* = 0.22$, the values 1.1212 and 12.5 were obtained from iteration for the ratios r/R and z*/ε, respectively.

Using these values, the maximum horizontal velocity can be expressed as $u_{max} = 0.2357\ \lambda\ R$. The maximum vertical wind is located at r = 0 and z = z_h, by definition, and is given by

$$Wmax = \lambda z * \left(e^{-(z_h/z*)} - 0.92\right)$$

A ratio of maximum outflow and downflow velocities can be formed

$$\frac{u_m}{w_m} = \frac{0.2357R}{z * (e^{-(z_h/z*)} - 0.92)}$$

The Scaling factor, λ, was determined by using either of equations 5 or 6 for horizontal or vertical velocity, and setting it equal to the maximum velocity, u_{max} or w_{max}, respectively. Solving for λ results in:

$$\lambda = \frac{w_m}{z * (e^{-(z_h/z*)} - 0.92)} = \frac{u_m}{0.2357R}$$

The velocity equations were easily converted to rectangular coordinates, as shown in the Appendix. Partial derivatives with respect to x, y, and z were obtained by differentiating the velocity equations, and are also listed in this Appendix.

DISCUSSION AND RESULTS

Vertical and horizontal velocity profiles for u and w are shown in Figures 6 and 7.

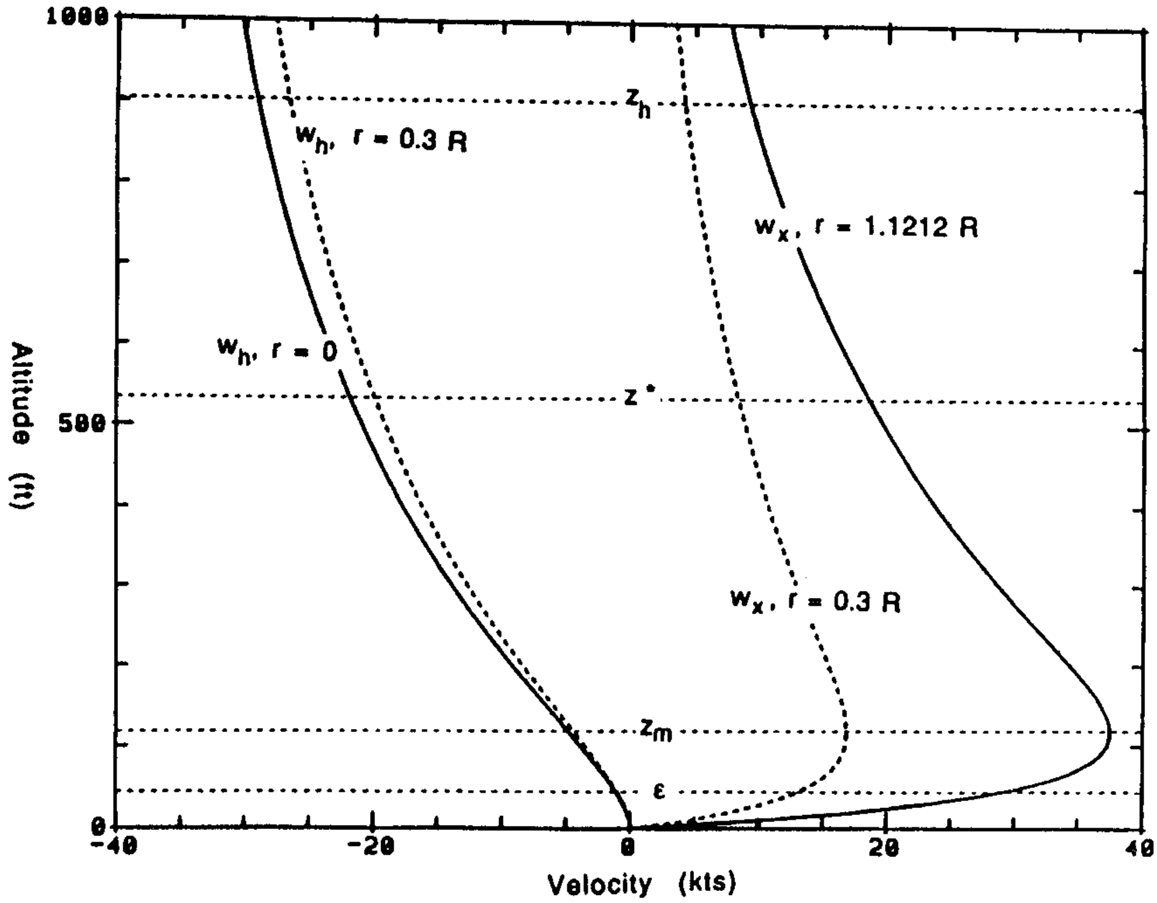


Figure 6 — Vertical Velocity Profiles for the Analytical Model

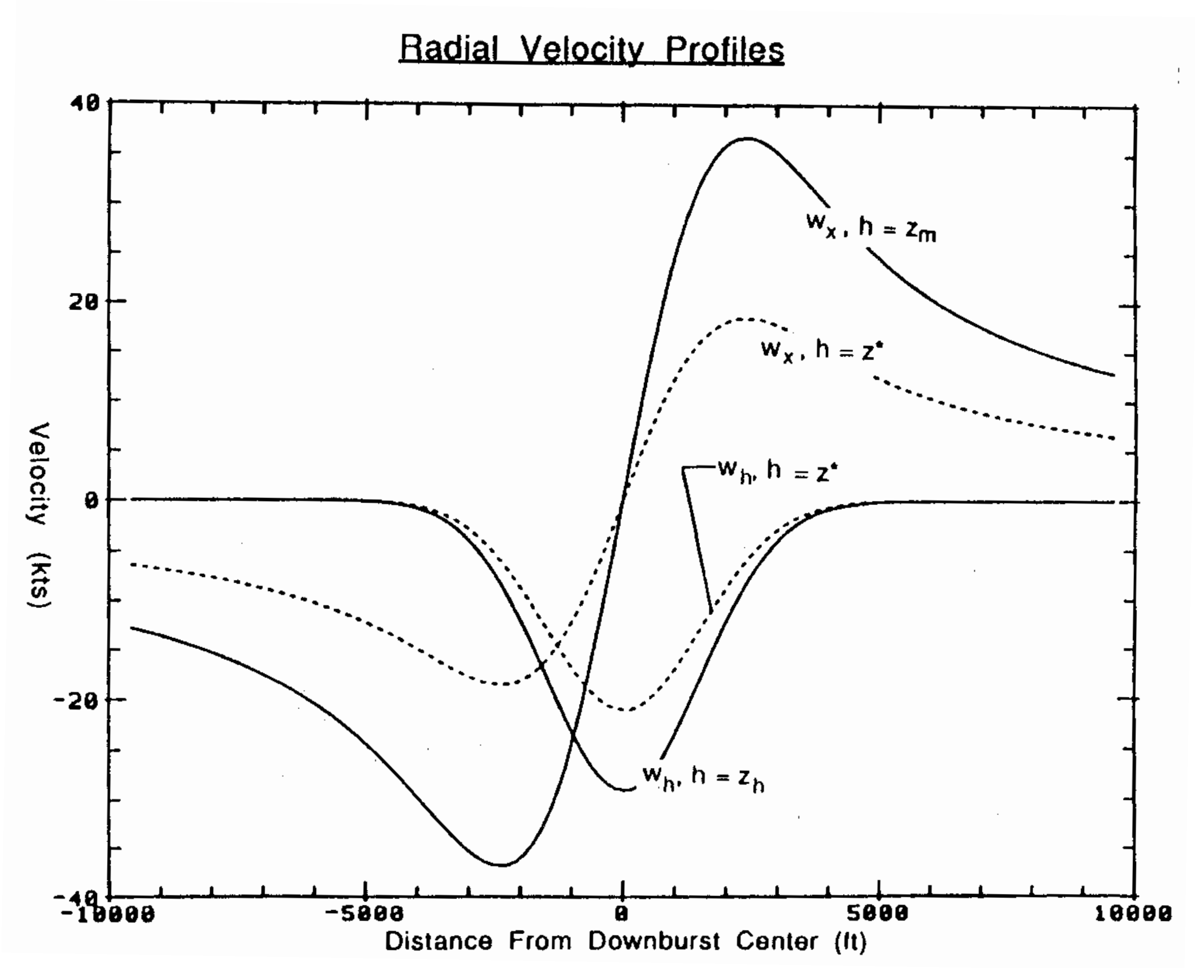


Figure 7 — Radial Velocity Profiles for the Analytical Model

Four profiles are shown for each component. The horizontal wind profiles in figure 6 were taken at the radios of peak outflow (r = 1.1212 R) and at about one-fourth that radius (r = 0.3 R), where the maximum outflow is approximately half the value at the peak outflow radius. The vertical wind profiles were taken at the radius of peak downflow (r = 0) and at r = 0.3 R. Horizontal wind and vertical wind profiles in figure 7 were taken at altitudes of h = z_m (maximum outflow), h = z* (half-maximum outflow), and h = z_h (depth of outflow).

This analytical model is compared with TASS, laboratory, and NIMROD data in figure 8. The figure shows that, when non-dimensionalised by the altitude of half-maximum outflow (z*) and by the maximum outflow (u = u_{max}), the analytical model agrees closely with the other data.

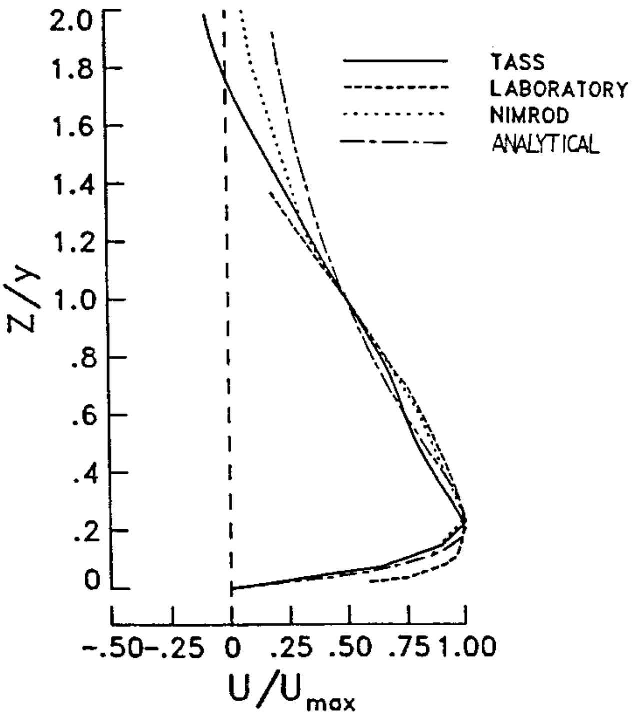


Figure 8 — Comparison of Wind Model Vertical Profiles

Different shears can be modelled by specifying four parameters, and the location of the downburst centre relative to the aeroplane flying through it. The four parameters are: 1) a characteristic horizontal dimension; 2) the maximum wind velocity; 3) the altitude of maximum outflow; and 4) the depth of outflow. The characteristic horizontal dimension specified is the radius of the downdraft column, noting that this is about 89 % of the radius of the peak outflow. The maximum wind velocity can be either horizontal or vertical.

CONCLUDING REMARKS

The analytic microburst model developed for use in real-time and batch simulation studies was shown to agree well with real-world measurements for the cases studied. The functions chosen for the model showed boundary-layer effects near the ground, as well as the peak and decay of outflow at increasing altitudes, and increasing downflow with altitude. The exponential increase and decay of the downflow and outflow (in the radial direction) are also characterised by the model. Equations for horizontal and vertical winds are simple and continuously differentiable, and partial derivatives in rectangular or cylindrical coordinates can be easily obtained by direct differentiation of the velocity equations. The governing equation for this system is the mass conservation law, and the analytic velocity functions developed here satisfied this condition. The model is sustained by a strong physical basis and yields high fidelity results, within the limitations of maintaining simplicity in the model, and variability of the microburst phenomenon. Parameterization of some of the characteristic dimensions allows flexibility in selecting the size and intensity of the microburst.

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[Amdt ETSO/16]

Appendix 3 to ETSO-C117b – Wind Field Model Coordinate System Transformation

ED Decision 2020/011/R

This Appendix describes the conversion of the velocity equations in Appendix 2 to rectangular coordinates.

Define intermediate variables to simplify written equations:

$$e_r = e^{-(r/R)^2} \qquad e_d = e_z - e_e$$

$$e_e = e^{-(h/\varepsilon)} \qquad e_c = z^*(1-e_z) - \varepsilon(1-e_e)$$

$$e_z = e^{-(h/z*)}$$

Horizontal and Vertical Velocities

$$W_X = \frac{\lambda R^2}{2r^2}(1-e_r)e_d x_{ad}$$

$$W_y = \frac{\lambda R^2}{2r^2}(1-e_r)e_d y_{ad}$$

$$W_h = -\lambda e_r e_c$$

Partial Derivatives

$$\frac{\partial w_x}{\partial x} = \frac{\lambda R^2 e_d}{2r^2}\left[e_r\left(\frac{2x_{ad}{}^2}{R^2} + \frac{2x_{ad}{}^2}{r^2} - 1\right) - \frac{2x_{ad}{}^2}{r^2} + 1\right]$$

$$\frac{\partial w_x}{\partial y} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}\left[e_r\left(\frac{1}{R^2} + \frac{1}{r^2}\right) - \frac{1}{r^2}\right]$$

$$\frac{\partial w_x}{\partial h} = \frac{\lambda R^2 x_{ad}}{2r^2}(1-e_r)\left[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}\right]$$

$$\frac{\partial w_y}{\partial x} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}\left[e_r\left(\frac{1}{R^2} + \frac{1}{r^2}\right) - \frac{1}{r^2}\right]$$

$$\frac{\partial w_y}{\partial y} = \frac{\lambda R^2 e_d}{2r^2}\left[e_r\left(\frac{2y_{ad}{}^2}{R^2} + \frac{2y_{ad}{}^2}{r^2} - 1\right) - \frac{2y_{ad}{}^2}{r^2} + 1\right]$$

$$\frac{\partial w_y}{\partial h} = \frac{\lambda R^2 y_{ad}}{2r^2}(1-e_r)\left[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}\right]$$

$$\frac{\partial w_h}{\partial x} = \frac{2\lambda x_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial y} = \frac{2\lambda y_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial h} = -\lambda e_r e_d$$

Other Relationships

From TASS $\quad \frac{z_m}{z^*} = 0.22 \quad \frac{z^*}{\varepsilon} = 12.5$

Maximums $\quad W_{x_{max}} = 0.2357\lambda R$

$W_{y_{max}} = W_{x_{max}}$

$W_{h_{max}} = \lambda z^* (e^{-(z_h/z^*)} - 0.92)$

(λ is determined from the above relationships)

$$\frac{W_{x_{max}}}{W_{h_{max}}} = \frac{0.2357R}{z^* (e^{-(z_h/z^*)} - 0.92)}$$

Variable List

z* = altitude where w_x is half the value of $w_{x\ max}$ (ft)

ε = characteristic height of boundary layer effects (ft)

z_h = depth of outflow (ft)

z_m = altitude of maximum outflow (ft)

λ = scaling parameter (s^{-1})

r = radial distance from aeroplane to downburst (ft)

h = altitude of aeroplane (ft)

R = radius of downdraft (ft)

x_{ad}, y_{ad} = x, y coordinates, aeroplane to microburst (ft)

$w_{x\ max}$, $w_{y\ max}$, $w_{h\ max}$ maximum winds, x, y, and h directions

[Amdt ETSO/16]

Appendix 4 to ETSO-C117b – Dryden Turbulence and Discrete Gust Model

ED Decision 2020/011/R

This Appendix contains data that defines the Dryden turbulence and discrete gust model to be used in conducting the tests specified in paragraphs 4(d)(7)(ii), 4(d)(7)(iii), 4(d)(8)(ii), and 4(d)(8)(iii) of Appendix 1 to this ETSO.

Dryden Turbulence Model

$$Fu(S) = SIGMAu * SQRT\ (TAUu/PI) * 1/(1 + TAUu*S)$$

$$Fv(S) = SIGMAv * SQRT \left(\frac{TAUv}{PI2}\right) * \frac{(1 + SQRT3*TAUv*S)}{(1 + TAUv*S)*(1 + TAUv*S)}$$

$$Fw(S)= SIGMAw * SQRT \left(\frac{TAUw}{PI2}\right) \frac{(1 + SQRT3*TAUw*S)}{(1 + TAUw*S)*(1 + TAUw*S)}$$

where:

SIGMAu, SIGMAv, SIGMAw are the RMS intensities;

TAUu = Lu/VA;

TAUv = Lv/VA;

TAUw = Lw/VA;

Lu, Lv, Lw are the turbulence scale lengths; VA is the aircraft's true airspeed (ft/sec);

PI = 3.1415926535;

PI2 = 6.2831853070 (2 times PI);

SQRT3 = 1.732050808 (square root of 3); and

S is the Laplace transform variable.

The following table lists SIGMAu, SIGMAv, SIGMAw, Lu, Lv, and Lw versus altitude. Extrapolation will not be used, and simulator altitudes outside the bounds of the turbulence list will use the data at the boundary.

Altitude (feet)	RMS Intensities (ft/sec)			Scale Lengths (feet)		
	Long	Lat	Vert	Long	Lat	Vert
100	5.6	5.6	3.5	260	260	100
300	5.15	5.15	3.85	540	540	300
700	5.0	5.0	4.3	950	950	700
900	5.0	5.0	4.45	1123	1123	900
1500	4.85	4.85	4.7	1579	1579	1500

The applicant shall demonstrate that the variance of their turbulence implementation is adequate.

Discrete Gust Rejection

Discrete gusts (in the horizontal axis) with ranges of amplitude and frequency (A and OMEGA) of the form [A(1 − cos OMEGAt)] shall be used.

The following table lists the values of A and OMEGA to be used (this simulates an approximate 15-knot gust condition):

A	OMEGA (rad/sec)	Approx. Gust Duration (sec)
7.5	2.10	3
7.5	1.26	5
7.5	0.78	8
7.5	0.63	10
7.5	0.52	12
7.5	0.42	15
7.5	0.31	20

[Amdt ETSO/16]

Appendix 5 to ETSO-C117b – Shear Intensity

ED Decision 2020/011/R

$$f(t) = \frac{\dot{W}_x}{g} - \frac{W_h}{V}$$

where

$\dot{W}_x$ = Horizontal component of the wind rate of change expressed in g units (1.91 kt/s = 0.1 g) (positive for increasing headwind).

W_h = Vertical component of the wind vector w (ft/s) (positive for downdraft).

V = True airspeed (ft/s).

g = Gravitational acceleration (ft/sec^2).

[Amdt ETSO/16]

Appendix 6 to ETSO-C117b – Wind Shear Simulation Model

ED Decision 2020/011/R

The following computer listing (written in QuickBasic) provides a simplified aircraft simulation model for evaluating the effectiveness of various guidance schemes. This simulation runs on a personal computer, and the results obtained using it have been found to be comparable to those obtained on a full six-degrees-of-freedom simulator. This model was developed by J. Rene Barrios of the Honeywell Company.

The Wind Shear Simulation Model (WSSM) is a point mass three-degrees-of-freedom mathematical model which simulates the motion of an aeroplane in a vertical plane. The equations of motion, which are described in the wind axes, include the wind components of velocity and acceleration so that the aeroplane dynamics during a wind shear encounter are accurately modelled. This model has been used by several investigators to study the behaviour of an aeroplane during wind shear encounters.

Note: The Wind Shear Simulation Model provided at the end of this Appendix is an example written in Microsoft QuickBasic. Other programming languages such as Microsoft FORTRAN, C, or assembly language are also acceptable.

The Equations of Motion

The motion of a constant mass point in the vertical plane may be described by four equations of state and a control variable. For an aeroplane, it is convenient to use an orthogonal reference frame which is attached to the frame of the aeroplane, and its x-direction points in the direction of motion. Such a reference frame is the relative wind reference frame.

The following equations model the states of the aeroplane in the wind axes:

Vdt = g[(T.csalf) − D)/W − sngam] − Wxdt.csgam − Wzdt.sngam (1)

Gdt = {g[(T.snalf + L)/W − csgam] + Wxdt.sngam − Wzdt.csgam}/V (2)

Hdt = V.sngam + Wz (3)

Xdt = V.csgam + Wx (4)

where:

Vdt	Rate of change of true airspeed in knots/second
G	Gravitational constant in knots/second
T	Total engine thrust in lb
csalf	cos (alpha)
alpha	Angle of attack in radians
D	Total drag in lb.
W	Gross weight in lb
sngam	sin (gamma)
gamma	Flight path angle in radians
Wxdt	Inertial wind shear x-component in knots/second
Gdt	Rate of change of gamma in rad/second
snalf	sin (alpha)
L	Total lift in lb

V	True airspeed in knots
Hdt	Altitude rate in knots
Wz	Inertial wind z-component in knots
Xdt	Ground speed in knots

In the above equations, the positive directions are upwards and forwards. This implies that tailwinds and updrafts are positive, while headwinds and downdrafts are negative. All the states can be determined from a given alpha; therefore, alpha is the control variable.

Since the model is that of a point mass, it is necessary to introduce the concept of alpha_command and actual alpha to account for the effect of the horizontal tail/elevator. This is done by introducing a lag between the alpha_command and the actual alpha. Therefore, any command that is given to the elevator or stabiliser can be interpreted as an alpha_command, which will cause a change in the angle of attack.

From equations 1, 2, 3 and 4, it can be seen that any change in alpha will produce a change in the longitudinal and normal accelerations, which in turn will change the states of the aeroplane.

The Path Control Function

The different segments of the trajectory flown by the WSSM are described by a series of alpha_commands, which are generated by the procedure explained below.

1. The aeroplane is trimmed for the initial conditions specified by the user. The initial conditions are usually specified as the altitude, gross weight, flaps, speed, flight path angle, and wind characteristics. The trimming operation consists in finding the angle of attack that satisfies the equations of state and will result in an unaccelerated motion.
2. After the initial trim, alpha_command must be specified for each segment of the trajectory, which usually consists of a climb or descent segment at constant speed or constant path angle, and guidance through wind disturbances. The wind disturbance is provided by wind models that can be selected at initialisation time.
3. In order to specify an alpha_command, the user must supply a subroutine where a quadratic function is defined in such a way that when minimised with respect to alpha, and constrained by the equations of state, the minimising alpha will produce the desired path in an optimal manner. For example, if we want to fly initially at a constant path angle, say 8 degrees, then the quadratic function may be defined by the expression:

– $$\mathrm{cst} = \left(\mathrm{gamma} + \mathrm{Gdt} * \mathrm{dt} - \frac{8}{57.3}\right)^2 \qquad (5)$$

where:

cst	Function to be minimised w.r.t alpha
dt	Time increment used in simulation in sec.
Gdt*dt	A predictive term which anticipates the change in gamma

Other expressions follow:

$$\mathrm{cst} = (\mathrm{V} + \mathrm{Vdt} * \mathrm{dt} - \mathrm{V\_cmd})^2 \qquad \text{Constant speed}$$

$$\mathrm{cst} = (\mathrm{alpha} + \mathrm{gamma} + \mathrm{Gdt} * \mathrm{dt} - \mathrm{pitch\_cmd})^2 \qquad \text{Constant Pitch}$$

The minimisation of the function cst is performed by a subroutine at each time frame and is totally transparent to the user, who has to supply only the objective function cst.

4. Each expression defining a different value of the objective function cst is called a 'LAW'. The user selects the guidance law to be used during the wind shear encounter at the time the menu is displayed. This method allows the user to compare different guidance laws under the exact same conditions.

The Wind Models

The WSSM has two types of wind models: the Dallas-Ft Worth accident wind field, simulated by a quad_vortex model, and the constant shear model, which is user defined via the initial conditions menu.

Plotting Capabilities

The WSSM can plot up to 3 runs with 10 parameters per run. The length of each run should be kept under 60 seconds. This feature allows the user to compare different trajectories by overlaying the results.

The Programme

The WSSM is written in Microsoft QuickBasic, which is a highly structured language with a very friendly full-page editor. QuickBasic is very convenient for development, since it allows the user to stop execution, change the programme and continue executing. It also interfaces with Microsoft FORTRAN, C, or assembly language.

The procedure suggested for this application is that the WSSM be compiled without subroutines DETECT and GUIDE. DETECT and GUIDE can be separately compiled and put in a library called WNDSHR.QLB. These external subroutines may be written in Microsoft FORTRAN, C, or assembly language.

Listing of Programme

```
'************ AIRCRAFT FLIGHT PROFILE SIMULATION **********
'
'
DECLARE SUB PLOT ( )
DECLARE SUB TAKEOFF ( )
DECLARE SUB EULER ( )
DECLARE SUB MCRBRST ( )
DECLARE SUB WINDS ( )
DECLARE SUB OPT ( )
DECLARE SUB MIN (DM, M2, C1, C2, C3, M)
DECLARE SUB BEGIN ( )
DECLARE SUB VSHAKER ( )
DECLARE SUB COST ( )
DECLARE SUB LIMIT ( )
DECLARE SUB RATES ( )
DECLARE SUB THRUST ( )
DECLARE SUB ATMOS ( )
DECLARE SUB PRINTS ( )
DECLARE SUB DRAGS ( )
COMMON SHARED FLPS%, GEAR%, GEAR$, CL, CD, LIFT, DRAG, ALPHA
COMMON SHARED SEC, ALT, DST, HDOT, ALF, GAM, GAMREF, GREF, G
COMMON SHARED WSALERT%, WXO, WL, WX, WXDT, WZ, WZDT, DFW
```

```
COMMON SHARED WV, LC%, GM, GREFF, NOSAVE, GMO
COMMON SHARED DELTA, ISA, T0, SPDSND, VT, VC, MACH, A0, TAT, TAMF
COMMON SHARED THRST, EPR, TFCT, APPFLG%
COMMON SHARED SNGM, CSGM, CSAL, SNAL, VDOT, WG, GDOT, XDOT
COMMON SHARED AWX, AWZ, AU, AZ, VG, GRND, KF1, GMIN, KF2
COMMON SHARED ACMD, OLDALF, DT, HP, LP, ALFLIM
COMMON SHARED LAW%, GMR, ASS, CST, VTO, GCMD
COMMON SHARED OUTFILE$, DM, ALT1, PL$, TTT, WXDTO, TDX, TSH, WZO, TDZ, TSV
COMMON SHARED GM1, VTP, THETA
COMMON SHARED ALFRTE, PLMFLG%
'********************************************
' MAIN PROGRAM *
'********************************************
START: '< ----------------<< RE-RUNS START HERE
CLOSE : CLEAR
COLOR 15, 1: CLS : VIEW PRINT
LOCATE 8, 23: PRINT "WINDSHEAR SIMULATION"
LOCATE 10, 23: PRINT "FOR "
LOCATE 12, 23: PRINT "BOEING 737/200 "
LOCATE 23, 23: PRINT "TYPE " + CHR$(&H22) + "I" + CHR$(&H22) + " FOR INFORMATION"
DO WHILE a$ = ""
a$ = INKEY$
LOOP
IF a$ = "I" OR a$ = "i" THEN
a$ = "": CLS
'---------------------- INFORMATION PAGE-----------------------------------------
LOCATE 2, 2: PRINT "BOEING 737/200 INFORMATON"
LOCATE 3, 2: PRINT "JT8D-17 ENGINES"
LOCATE 5, 2: PRINT "------------------------------------------------------------------------"
LOCATE 7, 2: PRINT "ALLOWABLE WEIGHT RANGES..................: 75,000 TO 120,000 POUNDS"
LOCATE 9, 2: PRINT "ALLOWABLE TAKEOFF FLAP SETTINGS.........: 1, 2, 5, 15, 20, 25 DEGREES"
LOCATE 11, 2: PRINT "ALLOWABLE LANDING FLAP SETTINGS.........: 30, 40 DEGREES"
LOCATE 13, 2: PRINT "TAKEOFF EPR AT SEA LEVEL, STD. DAY...: 2.1 "
LOCATE 15, 2: PRINT "REFERENCE WING AREA.......................: 980 SQUARE FEET"
LOCATE 17, 2: PRINT "REFERENCE TAKEOFF SPEED..................: V2 + 10"
LOCATE 19, 2: PRINT "REFERENCE LANDING SPEED..................: 1.3 Vs"
LOCATE 23, 2: PRINT "Press Any Key to Continue..."
DO: LOOP WHILE INKEY$ = ""
END IF
ANS$ = "2"
CLS
WHILE (ANS$ = "2")
LOCATE 10, 30: PRINT "Fly ..... 1"
LOCATE 12, 30: PRINT "Plot ..... 2"
LOCATE 14, 30: PRINT "Exit ..... 3"
```

```
LOCATE 18, 30: INPUT "Selection .....", ANS$
IF ANS$ = "2" THEN
CALL PLOT
COLOR 15, 1
CLS
END IF
WEND
IF ANS$ = "3" THEN END
CALL BEGIN 'GET DATA/INITIALIZE VARIABLES
CALL THRUST 'INITALIZE THRUST
CALL TAKEOFF 'INITALIZE TAKEOFF
CALL COST 'SUBROUTINE COST
CALL PRINTS 'SUBROUTINE PRINT
FOR ICL% = 1 TO TTT ' TTT IS THE RUN TIME IN SECONDS
CALL THRUST ' SUBROUTINE EPR/THRUST
CALL WINDS ' SUBROUTINE WINDS
' CALL DETECT ' SUBROUTINE WINDSHEAR DETECTION
' SUPPLIED BY USER
' MUST RESIDE IN LIBRARY WNDSHR.QLB
CALL OPT ' SUBROUTINE OPTIMIZE
CALL LIMIT ' SUBROUTINE ALPHA RATE
CALL EULER ' SUBROUTINE INTEGRATE
CALL ATMOS ' SUBROUTINE ATMOSPHERE
CALL PRINTS ' SUBROUTINE PRINT
IF ALT < 0 THEN EXIT FOR
NEXT ICL%
PRINT "RUN IS COMPLETE"
PRINT "TYPE " + CHR$(&H22) + "D" + CHR$(&H22) + " FOR RUN DATA"
a$ = ""
DO WHILE a$ = "" ' Wait for key to be pressed
a$ = INKEY$
LOOP
VIEW PRINT: COLOR 15, 4: CLS
IF a$ = "D" OR a$ = "d" THEN
a$ = ""
LOCATE 2, 2: PRINT "DATA FROM CURRENT RUN"
LOCATE 4, 2: PRINT "-------------------------------------------------------------"
LOCATE 6, 2: PRINT "GROSS WEIGHT: "; WG; " POUNDS"
LOCATE 7, 2: PRINT "ISA DEVIATION: "; ISA; " DEG C"
LOCATE 8, 2: PRINT "FLAP POSITION: "; FLPS%; " DEGREES"
LOCATE 9, 2: PRINT "GEAR POSITION: "; GEAR$
LOCATE 11, 2: PRINT "CONTROL LAW: "; LAW%
LOCATE 12, 2: PRINT "GAMMA REFERENCE: "; GAMREF
LOCATE 13, 2: PRINT "PITCH LIMITING: "; PL$
IF PL$ = "YES" THEN
```

```
LOCATE 14, 2: PRINT "MAXIMUM PITCH: "; HP * 57.3; " DEGREES"
LOCATE 15, 2: PRINT "MINIMUM PITCH: "; LP * 57.3; " DEGREES"
END IF
LOCATE 16, 2: PRINT "TIME OF RUN: "; TTT * DT; " SECONDS"
IF DFW = 1 THEN
LOCATE 17, 2: PRINT "DALLAS/FW Wind Model"
ELSE
LOCATE 17, 2: PRINT "HORIZ. WIND MAGNITUDE "; WXO; " KNOTS"
LOCATE 18, 2: PRINT "HORIZ. SHEAR MAGNITUDE: "; WXDTO; " KNOTS/SECOND"
LOCATE 19, 2: PRINT "HORIZ. SHEAR DURATION: "; TDX; " SECONDS"
LOCATE 20, 2: PRINT "VERT. WIND MAGNITUDE: "; WZO * 1.689; " FT/SECOND"
LOCATE 21, 2: PRINT "VERT. WIND DURATION: "; TDZ; " SECONDS"
LOCATE 22, 2: PRINT "--------------------------------------------------------------"
END IF
IF LEN(OUTFILE$) = 0 THEN OUTFILE$ = "NONE"
LOCATE 23, 2: PRINT "OUTPUT FILE: "; OUTFILE$
LOCATE 24, 2: PRINT "Press Any Key to Continue...."
DO: LOOP WHILE INKEY$ = "" 'Wait for key to be pressed
END IF
GOTO START
END
SUB ATMOS STATIC
'*********************************************************
' SUBROUTINE ATMOSPHERE *
'*********************************************************
STATIC THETA
L% = ALT > 36089!
FISA = 1.8 * ISA
IF ALT > 36089 THEN
TMP = .7519 * T0
DELTA = .2234 * EXP((36089! - ALT) / 20806)
ELSE
TMP = T0 - .0035662 * ALT
DELTA = (TMP / T0) ^ 5.256
END IF
TAMB = TMP + FISA 'TAMBient in deg. R
TAMF = TAMB - 459.7 ' " " F
THETA = TAMB / T0
SQRTH = SQR(THETA)
SPDSND = A0 * SQRTH
IF VT > 0 THEN MACH = VT / SPDSND
VC = A0 * SQR(5 * (((1 + MACH * MACH / 5) ^ 3.5 - 1) * DELTA + 1) ^ .28571 - 5)
TAX = (TMP + FISA) * (1 + .2 * MACH * MACH) 'Deg. R
TAT = 5 * (TAX - 459.7 - 32) / 9 'Deg. C
IF INKEY$ < > "" THEN PRINT : INPUT "Press ENTER to continue...."; XXX
```

```
END SUB
SUB BEGIN STATIC
CLS : VIEW PRINT
'<--------------------------------- DATA_INPUT ------------------------------>
PRINT
INPUT "OUTPUT FILE (DEFAULT IS NO FILE) "; OUTFILE$
IF OUTFILE$ = " " THEN
NOSAVE = 1
ELSE
NOSAVE = 0
END IF
' CONSTANTS USED IN CALCULATIONS:
A0 = 661.478599# 'Speed of sound at sea level in knots
G = 19.07583 'Gravitational constant in knots/sec
T0 = 518.67 'Standard temperature at SL in deg Rankine
DT = .25 'Simulation time step in seconds
' --------------------------------- INITIALIZATION OF VARIABLES--------------------------
GMIN = 0
VDOT = 0
ALT1 = 0
INPUT "TAKEOFF OR APPROACH (T/A) (Default is T)....."; ANS$
IF ANS$ = "a" OR ANS$ = "A" THEN
INPUT "ENTER ALTITUDE IN FEET (Default is 1000' . "; ALT1
IF ALT1 = 0 THEN ALT1 = 1000
APPFLG% = 1
TFCT = 1
END IF
ALT = ALT1
' ----------------------- CONFIGURTATION CONSTANTS-----------------------------------------
ASS = 16.5 'Stick Shaker alpha in degrees
ASS = ASS / 57.3 ' " " " "radians
' ------------------------------------------ GROSS WEIGHT ENTRY------------------------------------------
PRINT : INPUT "ENTER GROSS WEIGHT IN POUNDS (Default is 110000) "; WG
IF WG = 0 THEN WG = 110000! ' DEFAULT SETTING
FL% = 0
WHILE (NOT FL%)
INPUT "ENTER FLAPS SETTING (Default is 0)............"; FLPS%
SELECT CASE FLPS%
CASE 0, 1, 2, 5, 15, 20, 25, 30, 40
FL% = -1
CASE ELSE
FL% = 0
PRINT "Invalid flaps setting"
PRINT "Only 0, 1, 2, 5, 15, 20, 25, 30, & 40 are supported"
PRINT
```

```
END SELECT
WEND
IF FLPS% < 15 THEN GEAR% = 1
IF FLPS% = 15 THEN INPUT "GEAR UP OR DOWN (1/0) (Default is Down).....”; GEAR%
IF GEAR% = 1 THEN
GEAR$ = " UP"
ELSE
GEAR$ = " DOWN"
END IF
INPUT "ENTER ISA DEV. IN DEGREES C (Default is 0)......"; ISA
PRINT
CALL VSHAKER ' COMPUTE V2+10 FOR FLAPS<33 OR 1.3Vs FOR FLAPS>32
PRINT " CONTROL LAW SELECTION:"
PRINT
PRINT " Speed = 1.1* V_stall = 1"
PRINT " Alpha = Stick Shaker Alpha = 2"
PRINT " Horizontal Acceleration = 0 = 3"
PRINT " 15_Degree Pitch = 4"
PRINT " Theoretical HONEYWELL/SPERRY = 5"
PRINT " User Defined = 6"
PRINT
INPUT " SELECT CONTROL LAW ....................... "; LAW%
IF LAW% = 0 THEN LAW% = 5
PRINT : PRINT
' ----------------------------------- GAMMA REFERENCE INPUT----------------------------------
IF LAW% > 4 THEN
INPUT "ENTER GAMMA REFERENCE IN DEGREES (Default is 0)........."; GMR
PRINT
GAMREF = GMR
GMR = GMR / 57.3: GMIN = GMR
END IF
' --------------------------------------- PITCH LIMITING SELECTION---------------------------------------------
INPUT "PITCH LIMITING DESIRED (y/n) (Default is NO)..............."; PL$
IF PL$ = "Y" OR PL$ = "y" THEN
PL$ = "YES"
INPUT " MAXIMUM PITCH ALLOWED IN DEGREES "; HP
INPUT " MINIMUM PITCH ALLOWED IN DEGREES "; LP
HP = HP / 57.3: LP = LP / 57.3: PL% = 1
ELSE
HP = 100
LP = -100
PL% = 0
PL$ = "NO"
END IF
CLS
```

```
' ------------------------------------------------ TIME FOR RUN-----------------------------------------------------------------
PRINT
INPUT "ENTER TIME OF RUN IN SECONDS (Default is 45).............."; TTT
TTT = TTT / DT
IF TTT = 0 THEN TTT = 45 / DT ' DEFAULT SETTING
' -------------------------------------- WINDSHEAR SET UP-----------------------------------------------------
INPUT "DALLAS/FW Wind Model (y/n)...(Default is constant Shear)....."; ANS$
IF ANS$ = "Y" OR ANS$ = "y" THEN
DFW = 1
ELSE
DFW = 0
PRINT
INPUT "MAGNITUED OF HORZ. WIND IN KNOTS......(Head wind < 0)......"; WXO
INPUT "MAGNITUED OF HORZ. SHEAR IN KT/SEC. (Dec. Perf. > 0)......"; WXDTO
INPUT "DURATION OF HORZ. SHEAR IN SEC.............(Default is 0)......"; TDX
INPUT "TIME FOR SHEAR TO START IN SEC..............(Default is 0)......"; TSH
PRINT
INPUT "MAGNITUED OF VERT. WIND IN FT/SEC. (Down Draft < 0)......"; WZO
WZO = WZO / 1.689 'Convert to knots
INPUT "DURATION OF VERT. WIND IN SEC...........(Default is 0)........"; TDZ
INPUT "TIME FOR SHEAR TO START IN SEC...........(Default is 0)......"; TSV
PRINT
END IF
' -------------------- OTHER SET UPS-----------------------------------------------------
VT = VTO
WX = WXO
CALL ATMOS ' SUBROUTINE ATMOSPHERE
' ---------------------------------- HEADERS FOR SCREEN DISPLAY-----------------------------------------------------
CLS : PRINT
PRINT "TIME ALT HDOT VT ALPHA GAMMA PITCH GREF WXDT WZ VDOT ALRT"
PRINT "(SEC) (FT) (FPM) (KTS) (DEG) (DEG) (DEG) (DEG) (KT/S) (FPS) (KT/S)"
PRINT STRING$(75, "-"): VIEW PRINT 5 TO 25
'****************************************
' SUBROUTINE INIT_OUTPUT FILE *
'****************************************
IF NOSAVE THEN ' CREATE OUTPUT FILE
ELSE
OPEN "O", 2, OUTFILE$
FMT$ = " ###.## ##### ##### #### #### ## ###.## ###.## ###.##"
FMT$ = FMT$ + " ###.## ###.# ###.# ##.## "
END IF
END SUB
SUB COST STATIC
'**************************************************************
' SUBROUTINE COST *
```

```
'*************************************************************
CALL DRAGS ' SUBROUTINE DRAG & LIFT
CALL RATES ' SUBROUTINE RATES
IF LC% = 0 THEN 'Constant gamma segment
FCT = (GM + GDOT * DT - GMO) ^ 2
GREFF = 57.3 * GMO
ELSE 'All guidance laws
SELECT CASE LAW%
CASE 1 ' ---------------------------- 1.1*Vstall-----------------------------------
CST = (VT + VDOT * DT - 1.1 * 135) ^ 2
CASE 2 ' ---------------------------- Alpha = Ass-----------------------------------
CST = (ALPHA - ASS) ^ 2
CASE 3 ' ---------------------------- Ax = 0-----------------------------------
CST = (VDOT - VT * GDOT * GM + WXDT) ^ 2
CASE 4 ' ---------------------------- 15 Degrees-----------------------------------
CST = (GM + 3 * GDOT * DT + ALPHA - 15 / 57.3) ^ 2
CASE 5 ' ---------------------------- User Defined-----------------------------------
PRINT "Not defined"
STOP
CASE 6 ' ---------------------------- User Supplied-----------------------------------
'User must supply a subroutine called GUIDE
'which must reside in the WNDSHR.QLB Library
'GUIDE can have a list of arguments
'As an example
'ALF = 57.3*ALPHA
'PTH = 57.3 * (ALPHA + GM)
' units : ft fpm kt deg g's *
'CALL GUIDE(ALT, HDOT, VC, ALF, PTH, AU, AZ, CST)
END SELECT
END IF
' CST is the Cost Function to be minimized
END SUB
SUB DRAGS STATIC
'******************************************************
' SUBROUTINE DRAG FOR B737/200 *
'******************************************************
X = 57.3 * ALPHA + 1
CF5 = 0: CF4 = 0: CF3 = 0: CF2 = 0
SELECT CASE FLPS%
CASE 0
CF1 = .091
CF0 = .0156
CASE 1
CF3 = -1.164058E-04
CF2 = 2.48561E-03
```

CF1 = .0905781

CF0 = .062114

CASE 2

CF0 = .101198

CF1 = .110993

CF2 = −.0015162

CF3 = 1.8931E−04

CF4 = −7.1427E−06

CF5 = −4.2776E−09

CASE 5

CF0 = .192638

CF1 = .123509

CF2 = −.0051477

CF3 = 6.4968E−04

CF4 = −3.0891E−05

CF5 = 4.1291E−07

CASE 10

CF0 = .249855

CF1 = .114005

CF2 = 7.1207E−04

CF3 = −9.9541E−05

CF4 = 7.0431E−06

CF5 = −2.3773E−07

CASE 15

CF0 = .40149

CF1 = .118723

CF2 = −6.4877E−04

CF3 = 6.6281E−05

CF4 = −1.6113E−07

CF5 = −1.4278E−07

CASE 25

CF0 = .592655

CF1 = .122433

CF2 = −.0026365

CF3 = 3.5963E−04

CF4 = −1.5579E−05

CF5 = 1.0894E−07

CASE 30

IF X < 4 THEN

CF1 = .12

CF0 = .72

ELSE

CF3 = −1.651192E−04

CF2 = 4.16461E−03

CF1 = 8.337061E−02

```
CF0 = .8350316
END IF
CASE 40
IF X < 4 THEN
CF1 = .12
CF0 = 1.08
ELSE
CF3 = -1.689903E-04
CF2 = 3.733285E-03
CF1 = 8.483822E-02
CF0 = 1.201596
END IF
CASE ELSE
PRINT "Flaps "; FLPS%; " not available....."
END
END SELECT 'For CL computation
CL = ((((CF5 * X + CF4) * X + CF3) * X + CF2) * X + CF1) * X + CF0
SELECT CASE FLPS% 'Low Speed Drag Polars
CASE 0
D0 = .013285: D1 = .052868: D2 = -.07182: D3 = .071561
CASE 1
D0 = .026143: D1 = .022358: D2 = -.00083: D3 = .016338
CASE 2
D0 = .070346: D1 = -.0852: D2 =.097453: D3 = -.01207
CASE 5
D0 = .045214: D1 = -.0178: D2 =.04373: D3 = .002101
CASE 10
D0 = -.04266: D1 = .19643: D2 = -.1152: D3 = .03966
CASE 15
IF GEAR% = 0 THEN
D0 = .034954: D1 = .098892: D2 = -.04187: D3 = .020496
ELSE
D0 = -.02822: D1 = .174631: D2 = -.0874: D3 = .029566
END IF
CASE 25
D0 = -.10416: D1 = .327506: D2 = -.17059: D3 = .043313
CASE 30
D0 = .124697: D1 = -.03348: D2 =.055295: D3 = -.00311
CASE 40
D0 = .124925: D1 = .052537: D2 =.006912: D3 = .0058
CASE ELSE
PRINT "Flaps "; FLPS% " not available...."
END
END SELECT
CD = ((D3 * CL + D2) * CL + D1) * CL + D0
```

```
Q = 1451770 * MACH * MACH * DELTA 'B737/200
LIFT = Q * CL
DRAG = Q * CD
END SUB
SUB EULER STATIC
'******************************************************************************
' SUBROUTINE EULER'S PREDICTOR/CORRECTOR *
' (INTEGRATION SUBROUTINE) *
'******************************************************************************
DTH = DT / 3600: DTM = DT / 60: SEC = SEC + DT: VTP = VT
CALL RATES ' SUBROUTINE RATES <<PREDICTOR>>
ALT1 = ALT: HDOT1 = HDOT: ALT = ALT + HDOT * DTM
GM1 = GM: GDOT1 = GDOT: GM = GM + GDOT * DT
DST1 = DST: XDOT1 = XDOT: DST = DST + XDOT * DTH
VT1 = VT: VDOT1 = VDOT: VT = VT + VDOT * DT
CALL RATES ' SUBROUTINE RATES <<CORRECTOR>>
ALT = ALT1 + (HDOT1 + HDOT) * DTM / 2
GM = GM1 + (GDOT1 + GDOT) * DT / 2
DST = DST1 + (XDOT1 + XDOT) * DTH /2
VT = VT1 + (VDOT1 + VDOT) * DT / 2
END SUB
SUB LIMIT STATIC
'********************************************************************************************
' SUBROUTINE ALPHA DOT AND PITCH LIMIT *
'********************************************************************************************
ALPHA = OLDALF + .25 * (ACMD - OLDALF) 'Pitch dynamics
CALL DRAGS ' SUBROUTINE DRAG (REQ'D FOR RATE SUB CALL)
IF PLMFLG% = 0 THEN EXIT SUB
OLDGM = GM
PLIM% = 0
DO WHILE (PLIM% = 0)
CALL RATES ' SUBROUTINE RATES
X = ALPHA + OLGM + GDOT * DT
IF X > HP THEN ALPHA = .9 * ALPHA
IF X < LP THEN ALPHA = 1.1 * ALPHA
IF ALPHA > ALFLIM THEN
ALPHA = ALFLIM
PLIM% = 1
END IF
LOOP
END SUB
SUB MCRBRST STATIC
IF MU1 = 0 THEN
MU1 = -37141!
AV = 5500: H1 = 2500: G3 = 3: J1 = -700: J2 = 800: J3 = 6.5
```

```
MU2 = -20000
BV = 12000: H2 = 2000: N1 = 200: N2 = 2500: N3 = 4
WX = 5
IF ALT > 1000 THEN
PRINT
PRINT " DFW data not available above 1000'"
PRINT " Please start at or below 1000'"
END
END IF
END IF
X = 6078 * DST: Y = ALT: A1 = AV: A2 = BV
NX1 = Y - H1: DENX1 = (Y - H1) ^ 2 + (X - A1) ^ 2
NY1 = X + J2 - A1: DENY1 = (Y + J1 - H1) ^ 2 + (X + J2 - A1) ^ 2
NX2 = Y - H2: DENX2 = (Y - H2) ^ 2 + (X - A2) ^ 2
NY2 = X + N2 - A2: DENY2 = (Y + N1 - H2) ^ 2 + (X + N2 - A2) ^ 2
NX3 = Y + H1: DENX3 = (Y + H1) ^ 2 + (X - A1) ^ 2
NY3 = X + J2 - A1: DENY3 = (Y + J1 + H1) ^ 2 + (X + J2 - A1) ^ 2
NX4 = Y + H2: DENX4 = (Y + H2) ^ 2 + (X - A2) ^ 2
NY4 = X + N2 - A2: DENY4 = (Y + N1 + H2) ^ 2 + (X + N2 - A2) ^ 2
XX = MU1 * (-NX1 / DENX1 + NX3 / DENX3) + MU2 * (NX2 / DENX2 - NX4 / DENX4)
WX = WX + .65 * (XX - WX) + 2 * G3
IF DST = 0 THEN WXP = WX
ZZ = MU1 * (NY1 / DENY1 - NY3 / DENY3) * J3 + MU2 * (-NY2 / DENY2 + NY4 / DENY4) * N3
WZ = WZ + .65 * (ZZ - WZ)
IF DST = 0 THEN WZP = WZ
WX5 = WX4: WX4 = WX3: WX3 = WX2: WX2 = WX1: WX1 = WX
WZ5 = WZ4: WZ4 = WZ3: WZ3 = WZ2: WZ2 = WZ1: WZ1 = WZ
IF WCNT% < 4 THEN WXDT = (WX - WXP) / DT: WXP = WX
IF WCNT% < 4 THEN WZDT = (WZ - WZP) / DT: WZP = WZ
IF WCNT% > 3 THEN WXDT = (26 * WX5 - 27 * WX4 - 40 * WX3 - 13 * WX2 + 54 * WX1) / (70 * DT)
IF WCNT% > 3 THEN WZDT = (26 * WZ5 - 27 * WZ4 - 40 * WZ3 - 13 * WZ2 + 54 * WZ1) / (70 * DT)
IF ABS(WXDT) > 15 THEN WXDT = 15 * SGN(WXDT)
IF ABS(WZDT) > 15 THEN WZDT = 15 * SGN(WZDT)
WCNT% = WCNT% + 1
END SUB
SUB MIN (DM, M2, C1, C2, C3, M) STATIC
'**************************************************************
'SUBROUTINE MIN_CST BY LEAST SQUARES PARABOLA *
'**************************************************************
ALPHA = M2 + DM 'INCREMENT ALPHA
CALL COST 'SUBROUTINE COST
IF DM < 0 THEN
C4 = CST
ELSE
SWAP C1, C3
```

```
C5 = CST
END IF
ALPHA = M2 - DM 'DECREMENT ALPHA
CALL COST 'SUBROUTINE COST
IF DM < 0 THEN
C5 = CST
ELSE
C4 = CST
END IF
M = ABS(DM) * (14 * C1 + 7 * C4 - 7 * C5 - 14 * C3) / (20 * C1 - 10 * C4 - 20 * C2 - 10 * C5 + 20 * C3)
END SUB
SUB OPT STATIC
'****************************************************************************
'SUBROUTINE OPTALF - DETERMINES THE ALPHA REQD FOR CMD GAMMA *
'****************************************************************************
OLDALF = ALPHA: GM1 = GM
CALL ATMOS ' SUBROUTINE ATMOSPHERE
CALL RATES ' SUBROUTINE RATES
DM = 1 / 57.3 ' SET ALPHA INCREMENT TO 1 DEGREE
C1 = 1E+20
C2 = 1E+20
C3 = 1E+20
OPTFLG% = 0
WHILE (OPTFLG% = 0)
CALL COST ' SUBROUTINE COST
C3 = C2: C2 = C1: C1 = CST
M3 = M2: M2 = M1: M1 = ALPHA
LGC% = C1 > C2 AND C3 = 1E+20
IF LGC% THEN
DM = -DM ' Reverse search direction
C1 = C2: C2 = CST: M1 = M2: M2 = ALPHA
ALPHA =ALPHA + 2 * DM
ELSE
IF C1 < C2 THEN
L% = ABS(OLDALF - ALPHA) / DT > ALFRTE OR ALPHA > ALFLIM OR ALPHA < -.08
IF L% THEN OPTFLG% = 1
ALPHA = ALPHA + DM
ELSE
DM = DM / 2
CALL MIN(DM, M2, C1, C2, C3, M)'Fit parabola & find minimum
ALPHA = M2 + M 'This is the optimum alpha
OPTFLG% = 1 'Set flag to terminate
END IF
END IF
WEND
```

```
ALFLIM = ASS 'SET ALPHA LIMIT TO ALPHA STICK SHAKER
SELECT CASE LAW%
CASE 4
ALFLIM = ASS - .035 'LIMIT TO SS MINUS 2 DEG
CASE 5, 6
ALFLIM = ASS - KF2
CASE ELSE
END SELECT
IF ALPHA < -.08 THEN ALPHA = -.08
IF ALPHA > ALFLIM THEN ALPHA = ALFLIM
ACMD = ALPHA 'SET ALPHA COMMAND TO COMPUTED ALPHA
END SUB
SUB PLOT
'**************************************************************************************
'* PLOT ROUTINE *
'**************************************************************************************
REM $DYNAMIC
' TWO DIMENSIONAL PLOTTER
DEFINT I-L, N
DIM F$(3) ' file name array
DIM DTA(3, 250, 15) ' data array
DIM TY$(14) ' title array (dependant variable)
TITLE$ = "HONEYWELL WINDSHEAR SIMULATION" ' main title
TX$ = "Time (s)" ' X title
TY$(1) = "Altitude ft "
TY$(2) = "Alt Rate fpm "
TY$(3) = "T A S kts "
TY$(4) = "Alpha deg "
TY$(5) = "Gamma deg "
TY$(6) = "Pitch deg "
TY$(7) = "G_ref deg "
TY$(8) = "Hz Shear kps "
TY$(9) = "Vt Wind fps "
TY$(10) = "Vt rate kps "
TY$(11) = "W/S Flag "
NV = 12
CLS
LOCATE 3, 15: PRINT "Enter the names of the data files you wish to plot."
FOR NC = 1 TO 3
LOCATE 6 + 2 * NC, 25 ' input
PRINT "FILENAME "; NC; " "; ' filenames
INPUT ; F$(NC) ' containing
IF F$(NC) = " " THEN EXIT FOR ' data
NEXT NC
NC = NC - 1 ' number of curves to plot
```

```
LOCATE 20, 15: PRINT "Reading from disk........."
FOR I = 1 TO NC
CLOSE
OPEN "I", #1, F$(I) ' open file for input
NP = 0
DO
NP = NP + 1 ' number of points
FOR J = 1 TO NV
INPUT #1, DTA(I, NP, J) ' read data
NEXT J
LOOP UNTIL EOF(1)
CLOSE
NEXT I
DO ' display all selected parameters
DO ' prompt user until a valid parameter is selected
100 CLS
LOCATE 3, 20: PRINT "Select the parameter you wish to plot."
FOR I = 1 TO NV - 1
LOCATE 4 + I, 30: PRINT TY$(I); " = "; I
NEXT I
LOCATE 21, 30: INPUT "parameter number (0 to exit)"; PARAM%
IF PARAM% = 0 THEN
CLS
EXIT SUB ' return to calling program
END IF
LOOP UNTIL 1 <= PARAM% AND PARAM% <= 14 'end of select loop
PARAM% = PARAM% + 1
DX = 5 ' x axis grid increment
GOSUB 400 ' find maximum x and y values
IF PLTFLG% = 1 THEN
PRINT "No information to plot...."
PRINT "Press any key to continue..."
DO: LOOP WHILE INKEY$ = ""
GOTO 100
END IF
GOSUB 600 ' grid and titles
FOR I = 1 TO NC
GOSUB 1110 ' plot graph
NEXT I
DO
LOOP WHILE INKEY$ = ""
CLS : SCREEN 0
LOOP
'***************************************************************************************
400 '* MAX SUBROUTINE *
```

```
'*******************************************************************************************
'
MAXX = DTA(1, 1, 1)
MAXY = DTA(1, 1, PARAM%)
MINY = DTA(1, 1, PARAM%)
FOR I = 1 TO NC
FOR J = 1 TO NP
IF DTA(I, J, 1) > MAXX THEN MAXX = DTA(I, J, 1)
IF DTA(I, J, PARAM%) > MAXY THEN MAXY = DTA(I, J, PARAM%)
IF DTA(I, J, PARAM%) < MINY THEN MINY = DTA(I, J, PARAM%)
NEXT J
NEXT I
PLTFLG% = 0
DY = (MAXY - MINY) / 15
IF DY = 0 THEN
PLTFLG% = 1
DY = 5
END IF
MAG = 10 ^ (INT(LOG(DY) / LOG(10))): DY = DY / MAG
IF DY <= 5 THEN
DY = 5
ELSE
DY = 10
END IF
DY = DY * MAG
IF INT(MAXX / DX) < > MAXX / DX THEN MAXX = INT(MAXX / DX + 1) * DX
IF INT(MAXY / DY) < > MAXY / DY THEN MAXY = INT(MAXY / DY + 1) * DY
IF INT(MINY / DY) < > MINY / DY THEN MINY = INT(MINY / DY) * DY
NUMX = MAXX / DX
NUMY = (MAXY - MINY) / DY
RETURN
600
'*******************************************************************************************
'* GRID AND TITLES *
'*******************************************************************************************
'
CLS
SCREEN 2 ' 640*200 monochrome graphics
KEY OFF
'
FOR J = 0 TO NUMX
Z = J * 580 / NUMX + 59
LINE (Z, 10) - (Z, 170) ' vertical grid line
Z = J * 71 / NUMX + 7
a = DX * J
```

```
IF a < > 0 THEN ' adjustment for
D = INT(LOG(a) / LOG(10)) + 1 ' large numbers
IF D > 1 THEN Z = Z - D + 1
END IF
LOCATE 23, Z
PRINT a;
NEXT J
FOR J = 0 TO NUMY
Z = J * 160 / NUMY + 10
LINE (60, Z) - (640, Z) ' horizontal grid line
Z = 22 - J * 20 / NUMY
LOCATE Z, 2
Z = DY * J + MINY
AZ = ABS(Z)
IF INT(Z) = Z THEN
G$ = "######"
ELSEIF AZ < .1 THEN
G$ = "#.####"
ELSEIF AZ >= .1 AND AZ < 1 THEN
G$ = "##.###"
ELSEIF AZ >= 1 AND AZ < 10 THEN
G$ = "###.##"
ELSEIF AZ >= 10 AND AZ < 100 THEN
G$ = "####.#"
ELSE
G$ = "######"
END IF
PRINT USING G$; Z;
NEXT J
Z = (80 - LEN(TITLE$)) / 2 + 2
LOCATE 1, Z: PRINT TITLE$ ' print main title
LOCATE 24, 36: PRINT TX$; ' X axis title
LOCATE 8, 1 ' Y
FOR J = 1 TO LEN(TY$(PARAM% - 1)) ' axis
PRINT MID$(TY$(PARAM% - 1), J, 1) ' title
NEXT J
LOCATE 25, 10: PRINT "1"; ' curve
LINE (90, 195) - (130, 195)
LOCATE 25, 20: PRINT "2"; ' labels
FOR J = 0 TO 40 STEP 8
XX = 170 + J
PSET (XX, 195)
CIRCLE (XX + 80, 195) , 2
NEXT J
LOCATE 25, 30: PRINT "3";
```

```
RETURN
'*******************************************************************************************
'* PLOTTING ROUTINE *
'*******************************************************************************************
'
1110 FOR J = 1 TO NP
XX = 580 * DTA(I, J, 1) / MAXX + 60' calculate pixel X position
YY = 170 - 160 * (DTA(I, J, PARAM%) - MINY) / (MAXY - MINY)
IF J = 1 THEN GOTO 1170
IF I = 1 THEN LINE (XXOLD, YYOLD) - (XX, YY) ' line 1170
1170 XXOLD = XX: YYOLD = YY
IF I = 2 THEN PSET (XX, YY) ' point
IF I = 3 THEN CIRCLE (XX, YY), 2 ' circle
NEXT J
RETURN
END SUB
REM $STATIC
DEFSNG I-L, N
SUB PRINTS
'**********************************************************************
' SUBROUTINE PRINT TO SCREEN AND FILE *
'**********************************************************************
ACMDG = 57.3 * ACMD
ALF = 57.3 * ALPHA
GAM = 57.3 * GM
PITCH = ALF + GAM
WZX = 1.689 * WZ
IF NOSAVE = 0 THEN PRINT #2, SEC, ALT, HDOT, VT, ALF, GAM, PITCH, GREFF, WXDT, WZX, VDOT, WSALERT%
FMT1$ = "###.## #### ##### ### ###.# ###.# ###.# ##.# ###.# ###.# ###.# #"
PRINT USING FMT1$; SEC, ALT, HDOT, VT, ALF, GAM, PITCH, GREFF, WXDT, WZX, VDOT, WSALERT%
END SUB
SUB RATES STATIC
'**********************************************************************
' SUBROUTINE RATES *
'**********************************************************************
SNGM = SIN(GM): CSGM = COS(GM): SNAL = SIN(ALPHA): CSAL = COS(ALPHA)
VDOT = G * ((THRST * CSAL - DRAG) / WG - SNGM) - WXDT * CSGM - WZDT * SNGM
GDOT = G * ((LIFT + THRST * SNAL) / WG - CSGM) + WXDT * SNGM - WZDT * CSGM
GDOT = GDOT / VT
HDOT = 101.28 * (VT * SNGM + WZ)
XDOT = VT * CSGM + WX
AWX = VDOT + WXDT * CSGM + WZDT * SNGM 'Inertial Acc. along Wind_x axis
AWZ = VT * GDOT - WXDT * SNGM + WZDT * CSGN 'Inertial Acc. along Wind_z axis
AU = (AWX * CSAL + AWZ * SNAL) / G 'LONG. ACCEL. ->=?
AZ = (AWX * SNGM + AWZ * CSGM) / G 'VERT. ACCEL. UP=?
```

```
VG = XDOT
GRND = (VT * GM + WZ) / (VT + WX) 'Gamma w/r ground
KF1 = 1
GHAT = GMIN * (1 + WX / VT)
IF WZ > -30 AND WZ < -20 THEN KF1 = 1 + .025 * (WZ + 20)
IF WZ <= -30 THEN KF1 = .75
DGAM = 57.3 * (20 * GDOT - (GHAT - GRND + (1 - KF1) * WZ / 152 + 20 * GDOT))
IF DGAM < 0 THEN
KF2 = (2 + .4 * DGAM)
ELSE
KF2 = 2
END IF
IF KF2 < 0 THEN KF2 = 0
KF2 = KF2 / 57.3
END SUB
SUB TAKEOFF STATIC
'**********************************************************************
' SUBROUTINE INTIALIZE TAKEOFF *
'**********************************************************************
IF APPFLG% = 0 THEN
ALPHA = .12
WHILE (LIFT <= WG)
CALL DRAGS
ALPHA = ALPHA + .01
WEND
GM = (THRST - DRAG) / WG 'COMPUTE POTENTIAL GAMMA
ELSE
GM = -3 / 57.3
ALPHA = 2 / 57.3
CALL DRAGS
TFCT = 1
CALL THRUST
T = DRAG - .052 * WG
IF T < 0 THEN T = .2 * THRST
TFCT = T / THRST
THRST = T
END IF
GMO = GM
CALL RATES
END SUB
SUB THRUST STATIC
'*********************************************************************
' SUBROUTINE EPR/THRUST *
'*********************************************************************
' TAKE-OFF THRUST FOR JT8D-17 ENGINES
```

```
VE = 1.668 * VT
R00 = 14688.74: R01 = -.65187546#: R02 = 6.7371E-05
R10 = -13.9295: R11 = .000751143#: R12 = -1.5405E-07
R20 = .014643: R21 = 5.3444E-07: R22 = -4.8907E-10
AA0 = (R02 * ALT + R01) * ALT + R00
AA1 = (R12 * ALT + R11) * ALT + R10
AA2 = (R22 * ALT + R21) * ALT + R20
THRST = 2 * ((AA2 * VT + AA1) * VT + AA0) 'Temp. = 100 F
IF APPFLG% = 1 THEN
IF LC% = 1 AND TFCT < 1 THEN
GMO = .136
TSPL = 5.5
'Engine Spool Up Time
TFCT = TFCT + DT / TSPL
END IF
IF TFCT > 1 THEN TFCT = 1
ELSE
TFCT = 1
END IF
THRST = TFCT * THRST
" THRST = 2 * (((2.64159E-05 * VT + 5.110896E-03) * VT - 12.56476) * VT + 15550)
END SUB
SUB VSHAKER STATIC
'------------------------------------ COMPUTATION OF Vss AND V2-------------------------
V2 = 145
VTO = V2 + 10' SETS INITAL SPEED EQUAL TO V2 + 10
SELECT CASE FLPS%
CASE 10
IF VTO < 150 THEN VTO = 150 ' TAKEOFF
CASE 18
IF VTO < 148 THEN VTO = 148 ' FLAP
CASE 22
IF VTO < 147 THEN VTO = 147 ' SETTINGS
CASE 33
VTO = 63.11225 + .222468 * WG / 1000 ' APPROACH
CASE 42 ' FLAP
VTO = 62.67386 + .21744 * WG / 1000 ' SETTINGS
CASE ELSE
END SELECT
END SUB
SUB WINDS STATIC
'*******************************************************************
' SUBROUTINE WINDS *
'*******************************************************************
'
```

```
IF TDX > 0 THEN
T1 = 4
T2 = TSH
T3 = T1 + T2
T4 = -4
T5 = T3 + TDX
T6 = T5 - T4
B1 = 3 * WXDTO / T1 ^ 2
A1 = -2 * B1 / (3 * T1)
B2 = 3 * WXDTO / T4 ^ 2
A2 = -2 * B2 / (3 * T4)
IF SEC > T2 AND SEC < = T3 THEN
X = SEC - T2
WXDT = (A1 * X + B1) * X * X
END IF
IF SEC > T5 AND SEC < = T6 THEN
X = SEC - T6
WXDT = (A2 * X + B2) * X * X
END IF
IF SEC > T6 THEN WXDT = 0
WX = WX + WXDT * DT
END IF
IF TDZ > 0 THEN
T1 = 4
T2 = TSV
T3 = T1 + T2
T4 = - 4
T5 = T3 + TDZ
T6 = T5 - T4
B1 = 3 * WZO / T1 ^ 2
A1 = -2 * B1 / (3 * T1)
B2 = 3 * WZO / T4 ^ 2
A2 = -2 * B2 / (3 * T4)
IF SEC > T2 AND SEC <= T3 THEN
X = SEC - T2
WZ = (A1 * X + B1) * X * X
WZC = WZ
END IF
IF SEC > T5 AND SEC <= T6 THEN
X = SEC - T6
WZ = (A2 * X + B2) * X * X
WZC = WZ
END IF
KALT = (-.0000011 * ALT + .00212) * ALT - .0251
IF KALT < 0 OR ALT <= 0 THEN KALT = 0
```

```
KALT = 1
WZ = KALT * WZC
IF SEC > T6 THEN WZ = 0
WZDT = (WZ - WZ1) / DT
WZ1 = WZ
END IF
IF DFW = 1 THEN CALL MCRBRST 'DALLAS Model
END SUB
```

[Amdt ETSO/16]