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AEROSPACE RECOMMENDED PRACTICE

ARP 921

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Revised

FLIGHT TEST PROCEDURES FOR STATIC PRESSURE SYSTEMS INSTALLED IN SUBSONIC TRANSPORT AIRCRAFT

1. PURPOSE

The purpose of this document is to present recommendations for the flight testing of static pressure systems as installed in subsonic transport type aircraft.

2. SCOPE

This Aerospace Recommended Practice covers the test procedures and equipment for performing flight testing on pitot-static systems installed in subsonic transport type aircraft.

3. REGULATOR DOCUMENTS

3.1 Federal Aviation Agency Documents: The following documents, of the issue in effect on date of application for certification, form a part of this Aerospace Recommended Practice to the extent noted herein.

Federal Aviation Regulation - Part 25	Air Worthiness Standards: Transport Category Airplanes
Part 43	Maintenance, Preventive Maintenance, Rebuilding and Alteration
Part 91	General Operating and Flight Rules
Part 121	Certification and Operation: Air Carriers and Commercial Operators of Large Aircraft
Advisory Circular AC 43-203A	Altimeter and Static System Tests and Inspections, effective June 6, 1967

In the event of conflict between this document and the above documents, the regulatory documents shall apply.

3.2 SAE Documents: The following SAE documents, of the issue in effect on the date of application for certification, form a part of this Aerospace Recommended Practice to the extent noted herein:

ARP 920	Design and Installation of Pitot-Static Systems for Transport Aircraft
ARP 975	Maintenance Procedures for Pitot-Static Systems for Transport Aircraft

REAFFIRMED
OCT 1984

4. PITOT-STATIC SYSTEM GROUND TESTS

Prior to flight testing of any pitot-static system, such system should have been tested in accordance with the recommendations of ARP 975.

4.1 Prior to flight testing of any pitot-static system, at least one member of the flight crew should perform a visual inspection of the pitot-static system sensing orifice installations external to the aircraft. All pitot-(static) tube protective covers shall have been removed. There shall be no tape or other protective device covering flush static orifices. In addition, the aircraft should not be allowed to take off if there is any evidence of any deformity of the pitot-(static) tube or skin surrounding any flush static orifice. The static port installation and surrounding surface irregularities shall not exceed the tolerances as specified in ARP 975.

5. FLIGHT CALIBRATION AND TEST PROCEDURES

5.1 General: Several techniques have been developed for the calibration of aircraft pitot-static systems. The primary objective of these test methods is to determine by flight test the static system (position) error and airspeed error over the performance envelope (speed, altitude, weight range and configuration) for which the aircraft is designed.

The most important and widely used of these calibration techniques are described in subsequent paragraph. It is recognized that each technique is considered "standard" by some using organization (manufacturer or agency), and has certain advantages over other methods. However, in the interest of standardization, this ARP recommends and describes in detail only one technique, the trailing cone method.

5.1.1 Camera Fly-Over Calibration Method: In this calibration method the height of the aircraft under test is measured by photographing it as it flies directly overhead within an altitude range of 100 to 500 ft above the camera. Using the previously measured wing span of the aircraft and calibrated focal length of the camera, the height of the aircraft above the camera can be accurately determined. The atmospheric pressure is measured both at the camera site and in the aircraft using calibrated pressure instruments. Temperature is also measured at the camera site. Using the measured height, the true static pressure is computed for the fly-over elevation. The computed pressure is then compared with the actual pressure measured in the aircraft. The pressure difference resulting therefrom represents the static pressure error of the aircraft at the particular Mach number, airspeed, weight, flap position and the angle of attack during the fly-over.

5.1.2 Tower Fly-By Calibration Method: In this method the height of the test aircraft is measured by triangulation. The aircraft flies by a tower or tall building at a height within a range between 100 and 500 ft above the ground. The aircraft is sighted through a reference grid arrangement at or near the tower by a camera or eye piece located in the tower to determine elevation angle. The height of the aircraft above or below a fixed point in the tower is determined by triangulation. The horizontal distance of the aircraft from the tower must be accurately known. This is usually accomplished by having the aircraft fly down the centerline of a runway located in front of the tower.

5.1.3 Pacer Aircraft Calibration Method: In this method the pressure altitude of the test aircraft is measured while flying in close formation with a calibrated aircraft or pacer. Both aircraft contain calibrated pressure instruments. While flying in close formation at the same altitude and about one wing span apart (between wing tips), pressure data are simultaneously recorded in each aircraft. The pacer aircraft shall have a known pressure calibration as a function of airspeed and Mach number. Using this calibration and the difference in pressure recorded by the two aircraft, the pressure error of the test aircraft may be computed.

5.1.4 Radar Tracking Calibration Method: In this method the geometric altitude of the test aircraft is determined by ground based radar tracking equipment. The method is usually performed with the test aircraft flying at altitudes of 5000 ft or above. This method requires the use of calibrated pressure instruments in the test aircraft or tracking of weather balloon to determine atmospheric pressure at altitudes above the radar location. The test aircraft must be previously calibrated in at least one condition (such as at a given indicated airspeed), and that this or other calibrated conditions be utilized in the calibration of pressure versus elevation above the radar. After calibration of the space is performed by the test aircraft operating in the reference or previously calibrated mode or by the weather balloons, the aircraft is then flown through the test zone at various Mach numbers. As the position error of the aircraft changes with Mach number and/or angle of attack, the aircraft will increase or decrease altitude in order to maintain indicated airspeed. Differences in altitude between the reference and test condition converted to pressure, plus the position error at the reference condition then equals the pressure error at the test condition.

5.1.5 Trailing Cone Calibration Method: The Trailing Cone Method is the most inexpensive and easily used calibration method devised to date. In principle, the idea is to suspend a static reference far enough behind an aircraft so that the ports are not affected by the aerodynamic disturbances of the airframe. A differential pressure gage is connected between the aircraft static ports and the trailing cone reference system. Using measurements taken from these gages, the error in the static system may be determined. Using the trailing cone only one aircraft, namely the test aircraft, is involved. The combination aircraft/trailing cone can be flown at all altitudes and nearly all Mach numbers. Limitation and dependence upon ground based facilities is also minimized. The use of a lightweight trailing cone appears to overcome all serious deficiencies of other calibration methods and is herein recommended.

The trailing cone calibration method exhibits very little or no static pressure errors. These errors are a function of: (1) trailing cone configuration, (2) the distance aft of the aircraft at which the cone is trailed, and (3) the degree of air turbulence at the trailing cone position. It should be emphasized that careful handling and deployment as well as proper positioning distance behind the aircraft will virtually eliminate these small static errors.

5.2 Detailed Calibration Procedure - Trailing Cone:

5.2.1 General: A brief description of a trailing cone assembly is given in 5.2.2.1 and References (2), (3) and (4). Essentially, true static pressure is sensed by a set of holes placed around the circumference of a hollow tube at a distance ahead of the drag (trailing) cone. The distance of the static holes behind the aircraft needed to obtain true static pressure is dependent on the size and type of aircraft and location of engines (i.e., aft mounted engine). Extension length is approximately 100 to 130 ft for large turbo-jet aircraft and less for smaller aircraft. The distance should be determined for each aircraft configuration by flight test evaluation.

The hollow tube transmits the true static pressure (P_s) to an accurate, small range differential pressure gage and/or recorder which measures directly for static pressure position error (P_m-P_s); P_m is "measured" static pressure from the aircraft's static pressure source(s). A typical flight pattern for trailing cone flight calibration is shown in Figure 1; however, any suitable route may be used.

5.2.2 Airborne Test Equipment: The test equipment required in the aircraft for performance of this test is listed and described in the following paragraphs. The equipment should be monitored and the data recorded by a qualified individual.

5.2.2.1 Trailing Cone Assembly: An approved cone assembly should be installed on the test aircraft. Such an approved cone is one which has been approved for use by the F.A.A. It should consist of a length of flexible hollow tubing with a non-lifting drag cone at the end. Internal diameter of the tubing should be 0.312 in. (7.92 mm) or larger and the outside diameter should be approximately 0.375 in. (9.54 mm). A steel tubing approximately 2 ft (609.6 mm) long containing the static ports should be spliced into the flexible tubing forward or upstream from the cone. The static ports should be located about the circumference of the tubing and centered one foot (304.8 mm) from either or both ends of the tubing. The static port holes should be completely smooth and free from burrs, raised edges and dirt particles. The steel tubing section should be located such that the static ports are 10 to 15 ft (3.04 - 4.56 m) or 10 cone diameters ahead of the cone. A high strength steel wire or cable, approximately 1/16 in. (.019 mm) diameter through the length of the flexible tubing, may be used to carry the drag load of the cone. But in this event the O.D. shall be at least 0.500 in. (12.7 mm).

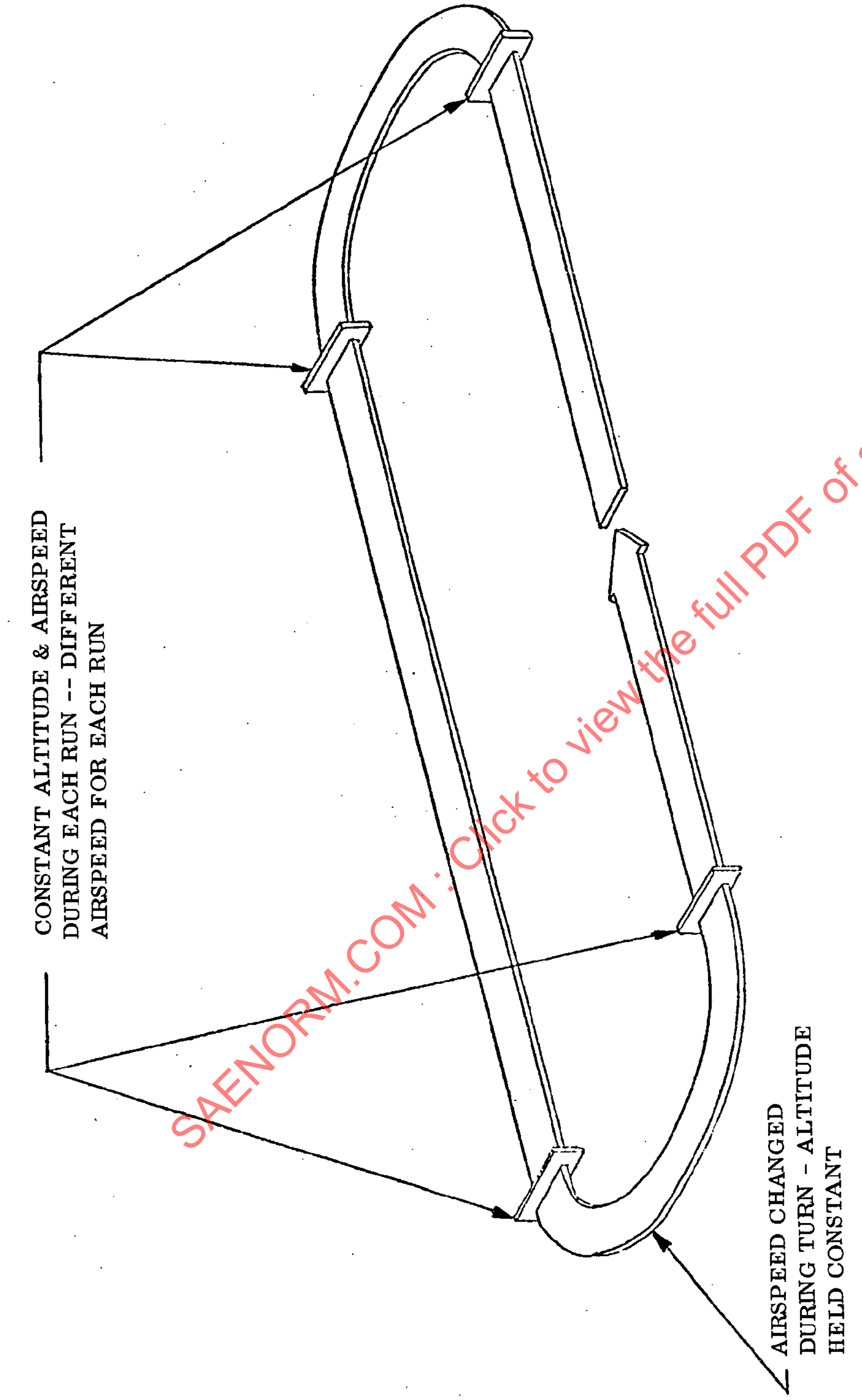
CONSTANT ALTITUDE & AIRSPEED
DURING EACH RUN -- DIFFERENT
AIRSPEED FOR EACH RUN
AIRSPEED CHANGED
DURING TURN - ALTITUDE
HELD CONSTANT

FIGURE I

5.2.2.1 (continued)

The trailing cone and attaching tubing/wire shall be connected to the aircraft in such a manner that there are no sharp tubing bends in the tubing, such as to impinge upon the free flow of air within the system, and the flexible tubing to steel tubing joint shall be smooth. Caution should be exercised to insure that such attachment will minimize the possibility of losing the cone in flight.

5.2.2.2 Differential Pressure Transducer: An accurate, small range differential pressure transducer or gage should be installed near the flight test engineer's station in an environmentally controlled area in the aircraft. The transducer or gage shall have been calibrated within the ten days preceding the test. It shall be of a design as to be capable of withstanding an overpressure of at least 25 in. Hg for pressure checking purposes.

The transducer should have a small internal volume in order to minimize pressure lag. An electrical signal from the pressure transducer shall be displayed on a meter at the observer's station. It may also be desirable to produce a DC signal output to a voltage recording device so that a continuous recording of the differential pressure can be made.

5.2.2.3 Airspeed Indicator: Airspeed shall be recorded throughout the test. For this purpose a precision airspeed indicator with a certified scale error calibration and accuracy of ± 0.1 knots should be installed at the flight test engineer's station in the aircraft. The indicator shall be selected for low hysteresis, good stability and repeatability and shall have been calibrated and certified within 30 days preceding the test.

> NOTE: The barometer used as a reference for calibration shall be compared to the standard at the National Bureau of Standards or to a standard traceable to the National Bureau of Standards, within a period not to exceed 18 months prior to use in calibrating the airspeed indicator for this test. The barometer shall be accurate with corrections to within 0.005 in. Hg.

The calibration chart obtained on the above noted airspeed indicator is needed for data reduction following the tests.

If the pilot's primary airspeed indicator meets all of the above criteria and is not compensated for position error by some form of artificial compensating means, it can be used in lieu of a special indicator installed at the flight test engineer's station. For recheck of static system calibration, the standard cockpit instrumentation may be used providing it meets the requirements specified herein.

5.2.2.4 Altimeter: Altitude shall be recorded throughout the test. For this purpose a precision altimeter shall be installed at the flight test engineer's station. The altimeter selected should exhibit good stability, repeatability, low hysteresis and small temperature dependence. The altimeter should be calibrated within ± 20 ft or 0.25% (whichever is greater) within 30 days preceding the test. The barometer used to calibrate the altimeter should meet the same criteria specified for the airspeed indicator. (See note included in paragraph 5.2.2.3 above.) If a recorder is used in lieu of a precision altimeter, it shall be calibrated to the equivalent altitude accuracy. The barometer set knob should be set at 29.9213 in. Hg and the knob either locked or removed for the duration of these tests. The resultant calibration chart showing altimeter instrument correction (ΔH_{ic}) versus uncorrected altimeter reading (H_i) is needed in data reduction. The calibration and operation of the special altimeter shall be at a setting of 29.921 in. Hg. If the pilot's primary altimeter meets the above criteria and is not compensated for position error by some artificial means, it can be used in lieu of the special altimeter installed at the flight test engineer's station.

For recheck of static systems calibration, the standard cockpit instrumentation may be used providing it meets the requirements specified herein.

5.2.2.5 Angle of Attack Indicator: Position errors for static port installations can vary considerably with variations in angle of attack of the aircraft. Obtaining the relationship of position error is desirable, and in some cases, necessary. The primary angle of the attack sensor system of the aircraft should be used.

NOTE: Most experimental category aircraft are equipped with an angle of attack sensor system for test purposes. However, the majority of production transport aircraft are not so equipped. Therefore, it may be necessary to periodically install such a sensor system for test purposes.

The angle of attack sensor system should be tested within 10 days prior to the test, in accordance with the manufacturer's recommendations. It should be accurate to ± .25 deg. and exhibit a resolution of .10 deg. or less. The output from the sensor system may be recorded on an oscillograph in addition to being displayed at the flight test engineer's station.

5.2.2.6 Flap Position Indicator: The static position errors for static port installations, especially flush fuselage installations can vary considerably with variations in inboard flap positions. Therefore, obtaining the relationship of position error with flap position, especially in the low speed region is desirable, and in some cases necessary. The aircraft's primary flap position indicator may be used for this purpose if it is graduated such that flap position can be read to within ± 0.5 deg. If not, the indicator should be temporarily replaced with one that may be read, and is accurate to 0.5 deg. or less. The indicator may be read out at the pilot's station or a separate indicator may be installed at the flight test engineer's station. An output signal from the flap position transmitter may also be recorded on a recording oscillograph, providing the recording accuracy is equal to, or better than, the ± 0.5 deg. noted above. For recheck of static system calibration, the standard cockpit instrumentation may be used providing it meets the requirements specified herein.

5.2.2.7 Recording Oscillograph/Photo Recorder: An airborne recording oscillograph, photo recorder or equivalent instrument which provides automatic and continuous recording of flight parameters should be installed in the test aircraft. This instrument, should an oscillograph be used, can be used to supplement or replace the special airspeed indicator and altimeters noted in 5.2.2.3 and 5.2.2.4. If the special IAS and altimeter is used, the photo recorder should be used to record their readings.

Either or both of these recorders may also be used to record pressure differential accurately from the pressure gage. To obtain the desired resolution, a 12 in. oscillograph is recommended. At least 10 in. of the 12 in. trace width should represent the differential pressure range of the pressure gage.

5.2.2.8 Voice Communication: Voice communication is needed between the aircraft's pilot and flight test engineer.

5.2.3 Flight Test Program:

5.2.3.1 Pre-Flight Procedure: The following installations are to be made in the aircraft prior to flight test.

5.2.3.1.1 The trailing cone assembly should be installed in the aircraft, preferably either from the top of the Vertical Stabilizer or from the center of the Fuselage Tail Cone. A flexible non-collapsible tubing with an internal diameter of 0.305 in. should normally be installed in the aircraft between the Trailing Cone Assembly and the flight test engineer's station for the transmission of static pressure from the trailing cone to the differential pressure gage. The length of the tubing and its internal diameter should be kept at a practical minimum to minimize lag in the system. For additional guidance the following narration is provided:

The above notation that tubing with an internal diameter of at least 0.305 in. should be used to connect the trailing cone to the differential pressure gage is not necessarily always consistent with obtaining a minimum lag system. This situation is due to the small effective diameter of the long cone tubing. The volume effect of the aircraft tubing on the cone tube can possibly override its own lag and actually cause an increased system lag over that obtainable with a smaller diameter aircraft tube.

The optimum diameter of the aircraft tube is a function of:

(1) Its own length
(2) Length and effective diameter of the cone tubing
(3) Volume of the differential pressure gage

Therefore, it cannot be specified precisely until these factors are known. It is quite probable, however, that for the usual trailing cone installation the optimum internal diameter of this tube will be 0.305 inch.

5.2.3.1.2 "T"-shaped pressure fittings should be placed in the primary static pressure and pitot pressure lines of the aircraft. Additional tubing should be installed between each "T" and the differential pressure gage, altimeter, air data computer, and airspeed indicator (or oscillograph). The tubing should be the same or equivalent to that noted in the paragraph above. If desired, the "T" fittings can be made a permanent part of the pitot-static systems. If so, they must be disconnected from the tubing noted above and capped when not used for calibration flights.

5.2.3.1.3 The special altimeter and airspeed indicator (or recording oscillograph if used), are to be placed at the flight test engineer's station in the aircraft. These indicating instruments should be connected to the special pitot and static pressure tubings. A second "T" fitting should be placed in the static pressure line to allow connection to the differential pressure gage.

5.2.3.1.4 The differential pressure gage should be placed at the flight test engineer's station and connected to the aircraft's static pressure line and trailing cone pressure line.

5.2.3.1.5 After installation of all pressure lines and indicating units, the pitot-static system should be purged, leak tested, and the pressure tested in accordance with ARP 975.

5.2.3.2 <u>Flight Calibration of Trailing Cone</u>: Successfully measuring true static pressure in flight is fundamental to the use of the trailing cone calibration method providing the proper techniques are used. Distance of the static ports behind the aircraft, needed to obtain true static pressure, must be known. Once this distance is determined for an aircraft type and configuration, it should remain the same for all additional aircraft of the same type and configuration, provided the same trailing cone assembly design is used.

5.2.3.2.1 Static pressure measured by the trailing cone is generally greater than true static pressure for distances close behind the aircraft and, in most instances, asympototically approaches true static pressure with increasing distances behind the aircraft. In determining the required trailing distance which may reach 100 ft or more, the flight test aircraft may use a take-up reel to extend and retract the trailing cone in flight. At a constant airspeed and altitude, the trailing cone should be extended in increments of 10 ft and the pressure differential between the trailing cone and the aircraft's primary static system should be measured at each increment. In most instances, true static pressure will be sensed by the trailing cone assembly when the differential pressure no longer varies with increasing distance behind the aircraft.

5.2.3.2.2 The distance between the aircraft and its trailing cone assembly at which true static pressure exists may also vary with airspeed, altitude, and aircraft configuration (i.e., clean or with flaps or gear extended). Therefore, tests should be conducted over the airspeed and altitude flight envelope of the aircraft for the various aircraft configurations anticipated to determine the minimum trailing distance for the cone assembly. This length can then be specified as the required trailing distance for that particular aircraft type and used for calibration of subsequent aircraft of the same type.

5.2.3.3 <u>Flight Test Coordination and Pilots' Orientation</u>: The flight test engineer in the test aircraft is responsible for coordination of the flight test program. (If the flight test engineer is not completely qualified, the flight engineer must coordinate the program.) The flight test engineer should be familiar with the operational manual of the aircraft under test. He must brief the pilot prior to flight on all applicable parts of section 5.2.3.4 of this document. The flight test engineer is also responsible for making out the flight test plan for himself and the pilot in a manner such as to specify the flight conditions for each test point required, and for establishing the sequence of tests. The number of test points required will depend upon the type of aircraft under test. The flight test engineer should review the Operational Manual for the test aircraft to determine the number of test points required for new certification or recalibration. As a minimum, the following test points should be taken for an original calibration of a new aircraft. These same test points should be taken after a major overhaul or modification of the airframe.

NOTE: It is recommended that the flight test plan be reviewed with the FAA and agreed upon by them prior to performing these tests.

5.2.3.3.1 Test Points: At least five test points with gear and flaps retracted should be taken at each altitude including:

(a) Minimum safe speed
(b) Maximum safe subsonic MACH number
(c) Three or more different intermediate speeds between minimum and maximum safe speeds.

5.2.3.3.1.1 A minimum of three data points should be taken at each test point. Tests should be conducted at three or more altitudes covering the operational envelope of the aircraft to determine dependence of static pressure position error on parameters such as angle of attack, airspeed, altitude, (including ground effect) and weight range.

5.2.3.3.1.2 Aircraft "Unclean" Configuration: At the lowest test altitude (sufficiently low to determine ground effect), and at 5,000 or 10,000 ft above the field elevation, the following aircraft configuration should be tested:

(a) Normal landing configuration with gear and flaps extended
(b) Normal approach configuration with gear and flaps extended
(c) Normal approach configuration with gear retracted.

5.2.3.3.1.3 Speed Range: For each configuration, tests should be run at three different speeds picked to span the operational limits of the aircraft. A minimum of three data points should be taken at each airspeed test point.

5.2.3.3.1.4 Recalibration: For recalibration check of an aircraft previously calibrated, it should only be necessary to conduct an abbreviated test. The flight observer should check the Flight Operations Manual and test objectives for requirements. The recalibration test plan should have been reviewed and approved by the FAA prior to the initiation of the tests.

5.2.3.3.1.5 Atmospheric Conditions: Insofar as possible, the tests should be conducted under nonturbulent atmospheric conditions (smooth air). Consideration should be given to conducting tests in the early part of the day, from about 3:00 a.m. to 8:00 a.m., and over large bodies of water or constant color terrain. It might be necessary for the pilot to search for smooth air during the testing period. Daylight is not needed for flying when using trailing cone and early pre-dawn hours usually provide the smoothest atmospheric conditions.

5.2.3.4 Flight Test Procedure: The flight test procedure for the trailing cone calibration method is described below. For original calibration, a special precision altimeter and a special airspeed indicator have been installed at the flight test engineer's station and that a visual meter is used to obtain readings from the special differential pressure gage. It is also assumed that the trailing cone assembly has been calibrated as explained in section 5.2.3.2 and that the distance between the trailing cone assembly's static ports and the aircraft is known. For recheck of a static system calibration, standard cockpit instrumentation may be used as covered in 5.2.2.4.

5.2.3.4.1 Take-Off: The pilot should take off and climb to the first test altitude. The trailing cone is then extended and the flight test engineer should then activate the special differential pressure gage and perform any necessary in-flight calibration of the visual meter for the pressure gage.

5.2.3.4.2 Test Run: The flight test engineer should direct the pilot to the approximate airspeed and altitude. The pilot should then use his altimeter and airspeed indicator to stabilize at the first test airspeed. After the airspeed has been established, the pilot should maintain constant power setting. Control surface movements should be kept to a practical minimum. The use of the autopilot is recommended for stabilization of previously calibrated large jet transports. The flight test engineer should then make any necessary final calibration adjustments of the visual differential pressure gage.