SAE
LAND SEA AIR SPACE
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AEROSPACE RECOMMENDED PRACTICE

ARP 920

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Revised

DESIGN AND INSTALLATION OF PITOT-STATIC SYSTEMS FOR TRANSPORT AIRCRAFT

1. PURPOSE

The purpose of this Aerospace Recommended Practice is to present recommendations for the design and installation of pitot and static systems for transport type aircraft. This document also makes recommendations for several system configurations and sets forth the acceptable quality control requirements and the means by which they are to be controlled.

2. SCOPE

This Aerospace Recommended Practice covers the design and installation requirements for pitot-static systems.

3. REGULATORY DOCUMENTS

3.1 Federal Aviation Administration Documents - The following document, of the issue in effect on date of application for certification, forms a part of this Aerospace Recommended Practice to the extent noted herein: Federal Aviation Regulation: Part 25 - Airworthiness.

Standards: Transport Category Airplanes. In the event of conflict between this document and FAR, Part 25, the regulatory document should apply.

3.2 Applicable Documents - The following 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:

Society of Automotive Engineers

AS 390	Pitot or Pitot-Static Pressure Tubes, Electrically Heated (Turbine Powered Sub-Sonic Aircraft)
AS 393	Airspeed Tubes - Electrically Heated.
ARP 921	Flight Test Procedures for Subsonic Transport Pitot-Static Systems
ARP 975	Maintenance Procedures for Pitot-Static Systems for Transport Aircraft

Federal Aviation Administration

Part 25	Airworthiness Standards: Transport Category Airplanes
AC 43-203	Advisory Circular- Altimeter and Static System Tests and Inspections

Radio Technical Commission for Aeronautics

120-61/00-108	Environmental Test Procedures for Airborne Electronic Equipment

Military Standards

MIL-STD-1247	Identification of Pipe, Hose, and Tube Lines for Aircraft, Missile, and Space Systems

4. GENERAL REQUIREMENTS

4.1 Materials and Workmanship

4.1.1 Materials - Materials should be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft.

4.1.2 Workmanship - Workmanship should be consistent with high grade aircraft manufacturing practice.

4.2 Compatibility of Components - If individual components of the pitot-static systems recommended herein are individually acceptable, but require matching for proper operation, they should be identified in a manner that will assure proper matching.

4.3 Environmental Conditions - The following environmental conditions have been established as design requirements unless more severe requirements are specified by the airframe manufacturer. The means of maintaining and testing to the following criteria are not covered in this recommended practice.

4.3.1 Temperature - When installed in accordance with the manufacturer's instructions, the individual components of the pitot-static system (i.e., sump valves, normal-to-alternate switching valves, etc.) should function over the range of ambient temperature shown in Column A below and should not be adversely affected following exposure to the range of temperature shown in Column B below.

Reciprocating Engine Powered Aircraft

Instrument Location	A	B
Heated Areas (Temperature Controlled)	0 to 55C	-50 to 71C
Unheated Areas	0 to 55C	-50 to 71C
Non-Pressurized	-46 to 71C	-50 to 71C

Turbine Powered Aircraft (Subsonic)

Instrument Location		
Pressurized Areas (Temperature Controlled)	0 to 60C	-50 to 71C
Non-Pressurized	-54 to 71C	-62 to 71C

Turbine Powered Aircraft (Supersonic)

Instrument Location		
Pressurized Areas (Temperature Controlled)	0 to 60C	-50 to 71C
Non-Pressurized Areas - No Temperature Control	-54 to 260C	-62 to 260C

4.3.2 Altitude - When installed in accordance with the manufacturer's instructions, the component should function and should not be adversely affected following exposure to a pressure and temperature range equivalent to -1000 to the maximum certificated altitude for the aircraft. The component should not be adversely affected when subjected to an ambient pressure of 50 in. (1280 mm) and 0.8 in. (20.51 mm) of mercury absolute.

4.3.3 Vibration (Reciprocating Engine Powered Aircraft) - When installed in accordance with the manufacturer's instructions, the component should function and should not be adversely affected when subjected to vibrations of the following characteristics.

4.3.4 Humidity - The component should function and should not be adversely affected following exposure to any relative humidity in the range from 0 to 95% at a temperature of approximately 70C.

4.3.5 Explosion Category - The system component, when intended for installation either in uninhabited areas of non-pressurized aircraft or in non-pressurized areas of pressurized aircraft, should not cause an explosion when operated in an explosive atmosphere. The component should meet the requirements applicable to the explosion category below. Specifically, any component which can be an ignition source and is intended for installation in an area in which combustible fluid or vapor may result from abnormal conditions, e.g. fuel line leakage, should meet the requirements of Category I. If the intended location is an area where combustible fluid or vapor can occur during normal operation, e.g. fuel tank, the instrument component should meet the requirements of Category II listed below:

Category	Definition
I	Explosion proofed: case not designed to preclude flame or explosion propagation.
II	Explosion proofed: case designed to preclude flame or explosion propagation.
III	Hermetically sealed.
IV	Instrument not capable of causing an explosion.

4.3.6 Fire Hazard - The system should be so designed as to safeguard against hazards to the aircraft in the event of malfunction or failure and the maximum operating temperature of surfaces of any instrument component contacted by combustible fuel or vapor should not exceed 200 C due to self heating.

All materials should be non-combustible and should not liberate gases or fumes which will result in such cor-

Instrument Location in Airframe	Cycles Per Sec.	Max. Double Amplitude (In.)	Maximum Acceleration
Wings and Empennage	5-2000	0.010	.25g
Fuselage	5-55	0.020	3.0 g
Panel (Vibration Isolated)	5-55	0.010	1.5 g

Vibration (Turbine Powered Subsonic Aircraft) - When installed in accordance with the manufacturer's instructions, the component should function and should not be adversely affected when subjected to vibrations of the following characteristics:

Instrument Location	Frequency Cycles Per Sec.	Max. Double Amplitude (In.)	(Peak) Maximum Acceleration
Wings, Empennage	5-2000	.030	5.0 g
Fuselage	5-2000	.020	3.0 g
Flight Deck Area	5-2000	.010	.25g

rosion as to cause malfunction of equipment, nor should toxic gases or fumes that are detrimental to performance of the aircraft or health of personnel be liberated under the operating conditions specified herein.

4.3.7 Radio Interference - The system should not be a source of objectionable interference under operating conditions at any frequencies used on the aircraft, either by radiation, conduction or feedback in any electronic equipment installed in the same aircraft as the instruments in accordance with RTCA Report 120-61/DO-108, latest revision.

4.3.8 Magnetic Effect - The magnetic effect of the system components should not adversely affect the performance of other instruments installed in the same aircraft.

4.4 General System Design and Installation - Each aircraft should be fitted with a minimum of two pitot and three static systems. Static ports or systems should be provided in manifold pairs and so designed and installed as to minimize the effects of aircraft sideslip (YAW). Fig. 1, 2 and 3 show system configurations which have been approved for use in specific aircraft and which may be used as a guide to the system designed.

4.4.1 Pitot (Total Pressure) System - Each aircraft should be equipped with a minimum of two pitot systems. These systems should be identified as:

A. Pitot System (Pilot's)
B. Pitot System (First Officer's)
C. Auxiliary Pitot System (if required by para. 4.4.1.3)

4.4.1.1 Captain's Pitot System - The captain's pitot system should be connected to his airspeed indicator. In aircraft equipped with machmeters, air data computers and/or altitude encoders, the captain's equipment should be connected to his pitot system. In aircraft equipped with only one air data computer and/or altitude encoder, it should be connected to the captain's pitot system.

4.4.1.2 First Officer's Pitot System - The first officer's pitot system should be connected to his airspeed indicator. In aircraft equipped with machmeters, maximum allowable speed switch, air data computers and/or altitude encoders, the first officer's equipment should be connected to his pitot system.

In aircraft equipped with automatic flight control systems (autopilots), flight data recorders and pitch trim compensators, etc. such equipment may be connected to the first officer's pitot system. However, means must be provided to permit either manual or automatic disconnect of such auxiliary equipment from the basic system supplying pitot pressures to the first officer's airspeed and Mach indicators in the event of a failure in any of the auxiliary equipment or a leak in the associated plumbing.

4.4.1.3 Auxiliary System(s) - Should an additional independent auxiliary pitot system(s) be installed, such auxiliary system should be connected to the automatic flight control system, flight data recorder, pitch-trim compensators and any other equipment that may require pitot pressure. Should equipment connected to auxiliary static systems require pitot (dynamic pressure) inputs, such auxiliary pitot systems should be installed.

4.4.2 Static System - Each aircraft should be equipped with a minimum of three static systems. These systems should be identified as: captain's, first officer's and alternate. Should additional static systems beyond the ones specified be used, they should be identified as auxiliary systems in terms of the use to which they are put (e.g., "Autopilot Static System", etc.).

Caution should be exercised, however, to avoid connecting too many systems to each static system. The number of transducers which can be connected to each system is dependent upon their volume and the resultant effect upon lag (see para. 4.6.4) when connected thereto.

4.4.2.1 Captain's Static System - The captain's static system should be connected to his altimeter, airspeed indicator, and rate of climb indicator if installed. The captain's static system should also be equipped with a selector valve permitting transfer of the captain's instruments to the alternate static system. In aircraft equipped with machmeters, air data computers and/or altitude reporting systems, the captain's equipment should be connected to his static system. In aircraft equipped with only one air data computer and/or altitude reporting system, it should be connected to the captain's static system.

4.4.2.2 First Officer's Static System - The first officer's system should be connected to his altimeter, airspeed indicator and rate of climb indicator. The first officer's static system should also be equipped with a selector valve permitting transfer of the first officer's instruments to the alternate static system. In aircraft equipped with machmeters, maximum allowable speed switch, air data computers and/or altitude reporting systems, the first officer's equipment should be connected to his static system.

4.4.2.3 Alternate Static System - For purposes of reliability, an alternate static system should be installed in each aircraft. The alternate system should be provided with independent captain and first officer's selector valves to permit the system to be independently or simultaneously connected to the captain and first officer's flight instruments in lieu of their primary system (see para. 4.4.2.1 and 4.4.2.2).

4.4.2.4 Auxiliary Static System(s) - Auxiliary static systems are identified as any static system installed in the aircraft other than those previously identified as the captain's, first officer's and alternate systems. As many auxiliary static systems as deemed absolutely necessary to insure aircraft safety should be used in the aircraft. The auxiliary static system(s) may be used to provide static pressure to the autopilot, flight data recorder, pitch-trim compensator, cabin pressure con-

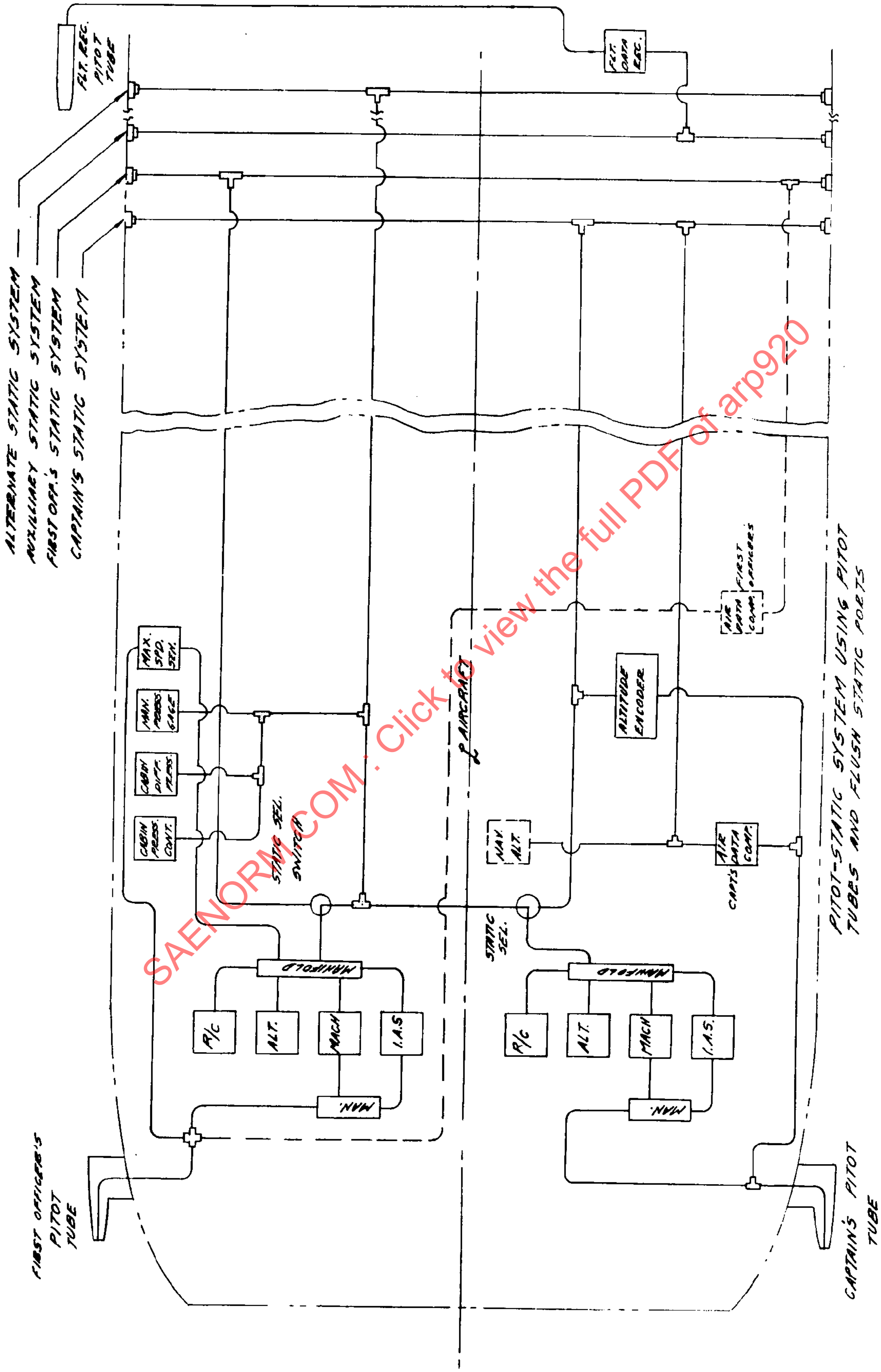

FIGURE 1 - SCHEMATIC — PITOT-STATIC SYSTEM

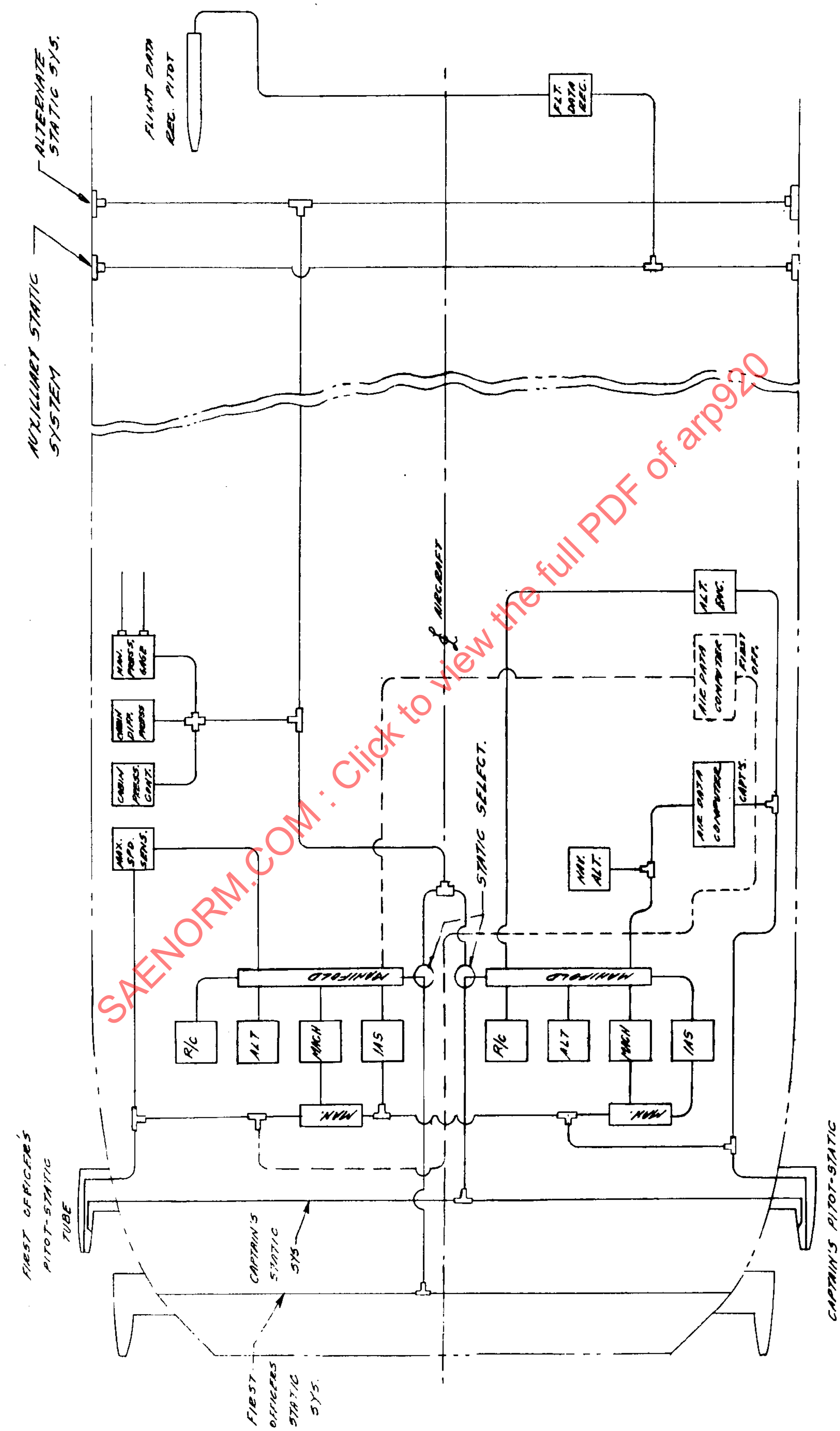

FIGURE 2 - SCHEMATIC -- PITOT-STATIC SYSTEM USING PITOT-STATIC TUBES

troller*, cabin differential pressure gauge, etc. or any combination thereof. Each auxiliary static system should be identified.

*NOTE: A separate static system should be provided for cabin pressure control equipment of the bleeding type (see para. 4.5.2.4).

4.5 Specific System Design

4.5.1 Pitot (Total Pressure) Systems

4.5.1.1 Accuracy - The total pressure as measured by either the captain or first officer's and/or auxiliary pitot systems should not differ from the true pitot (total) pressure by more than 1.0% at any speed, altitude, angle of attack, angle of sideslip or aircraft configuration within the approved operating envelope of the aircraft. In addition, the first officer's or auxiliary pitot systems should not differ from the captain's system by more than 0.5% when the aircraft is flying so as to exhibit no detectable sideslip.

4.5.1.2 Pitot Tubes - Pitot (total) pressure should be obtained either from a pitot or pitot-static pressure tube or probe. In addition to the requirements specified herein, their basic design should meet the requirements of AS 393 or AS 390.

a. Pitot Tube Total Pressure Entry - The shape of the tube's entry should be such as to minimize errors due to the local airflow into and around the tube.

b. Anti-Icing/De-Icing

(1) Pitot Tube Anti-Icing/De-Icing - Each pitot or pitot-static tube should be provided with an internal anti-icing/de-icing heater. Such anti-icing/de-icing should be accomplished by either electrical or pneumatic means, and should be so located and of sufficient heat that when activated it will meet the performance requirements of AS 390 and AS 393.

(2) Strut Anti-Icing/De-Icing - Where a strut or mast is employed for mounting of the pitot or pitot-static tube, an electrical or pneumatic heater should be provided in the leading edge if needed to maintain system accuracy and to prevent or eliminate the build-up of ice. The strut anti-icing/de-icing heater should be connected so as to operate concurrently with the pitot or pitot-static tube anti-icing/de-icing system.

(3) Ground Operation of Anti-Icing/De-Icing Heaters - The pitot or pitot-static tube and mast anti-icing/de-icing heater systems should be designed such that no damage to the tube or mast should result from allowing power to be applied to the heaters for a period of 5 hr at any time when the aircraft is on the ground.

(4) Heater Power Monitoring - Some means should be provided to indicate to the flight crew that electrical current, if used, is being used by the anti-icing/de-icing heaters.

c. Drainage Provisions: The pitot or pitot-static tube should include water drainage provisions. Such drainage provisions should be in the form of holes so located as to allow drainage when the aircraft is on the ground. A tube which is otherwise symmetrical about its axis should have the mounting holes arranged assymmetrically so as to assure that the tube can only be installed with the drain hole(s) at the bottom.

The diameter of the drain hole(s) should be such as to reduce the blocking effect of capillary action of water in the drain holes. The cross-sectional shape of the drain holes should be such as to prevent them from causing an error in excess of the total system error of para. 4.5.1.1. An example of such a drain hole cross section is shown in Fig. 3.

4.5.1.3 Pitot Tube Location - Each pitot or pitot-static tube should be so located as to provide pitot (total) pressure and static pressure (as applicable) with a minimum of interference effects from the aircraft. The mounting location selected should be as free as possible from the effects of boundary layer, angle of attack or angle of sideslip, access doors, radomes, landing gear doors, landing flaps, fluids draining from the aircraft or similar conditions. The pitot or pitot-static tube should be so located as to minimize the possibility of damage due to encounters with ground equipment or personnel. They should also be so located as to minimize their use as handles or steps by maintenance or flight personnel.

a. Pitot Tube Spacing - Pitot or pitot-static tubes should be spaced a sufficient distance apart so that a single object (such as a bird) cannot occlude or damage more than one tube, nor should the flow field or wake of one tube affect the flow field or accuracy of another tube.

b. Accuracy of Pitot Tube Mounting Provisions - When the pitot (pitot-static) tube is attached directly to the aircraft structure, the mounting provisions of both the tube and the aircraft structure should be held to sufficiently close tolerances to allow routine replacement of the tubes without the need for special aligning procedures or tools such as templates, bubble protractors, etc.

When the pitot (pitot-static) tube is mounted on a boom or mast which would normally be considered an integral part of the aircraft, the mounting provisions of both the tube and the mating portion of the boom or mast should be held to sufficiently close tolerances to allow routine replacement of the tube without the need for special aligning procedures or tools.

NOTE: Where a boom or mast is provided as part of the airplane, a simple means should be provided for checking its alignment.

4.5.2 Static Pressure Systems - General System Design

4.5.2.1 Static Pressure Accuracy

a. Federal Aviation Regulation Accuracy Requirements - Para. 25.1325 of Part 25 of the Federal Aviation Regulations specified the accuracy requirements for static systems as required by the Federal Aviation Administration (see Fig. 4).

b. Operator's Accuracy Requirements - The operator's requirements for static system accuracy are some-

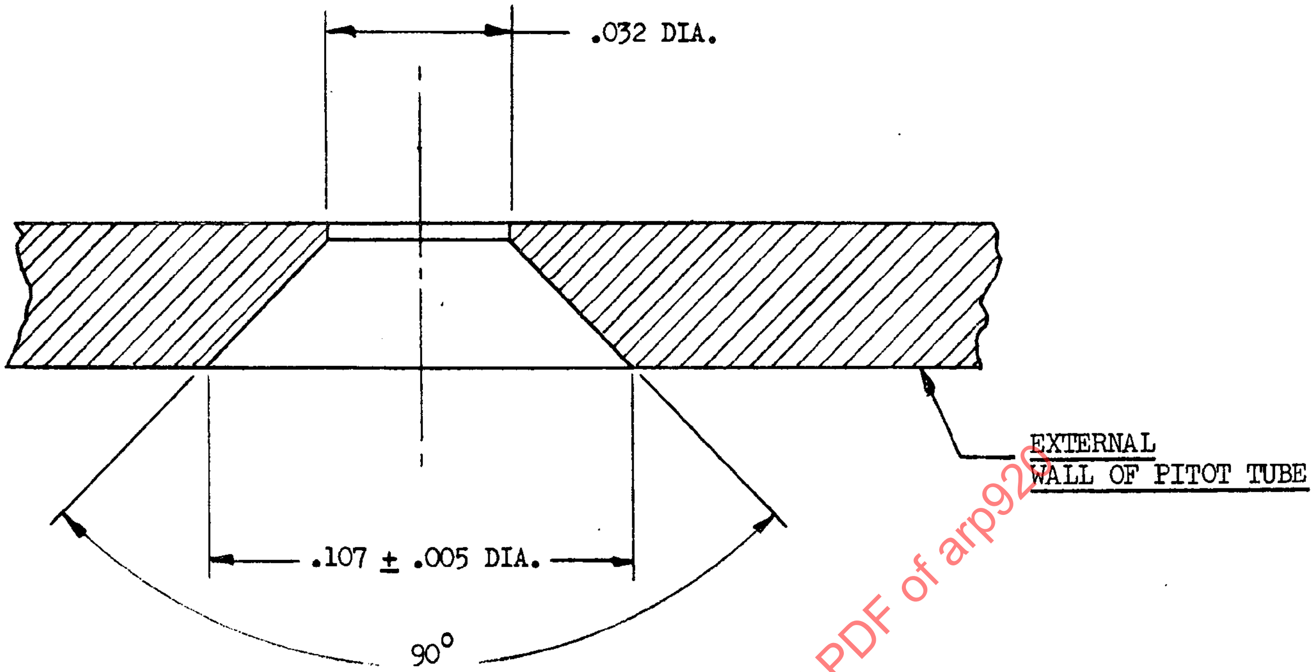

FIGURE 3 - DRAIN HOLE CROSS SECTION

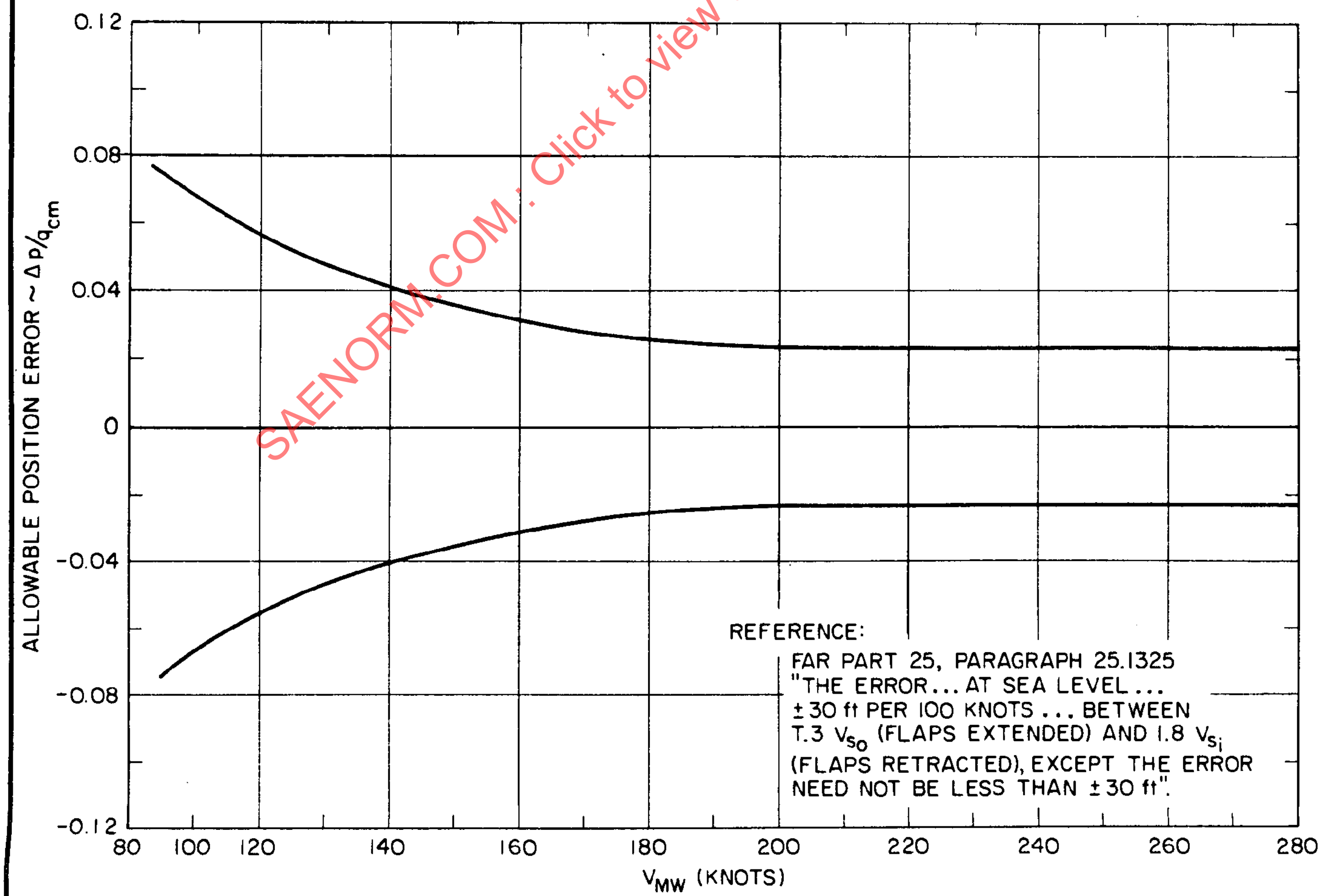

FIGURE 4 - FAA ALLOWABLE STATIC PORT ALTITUDE ERROR

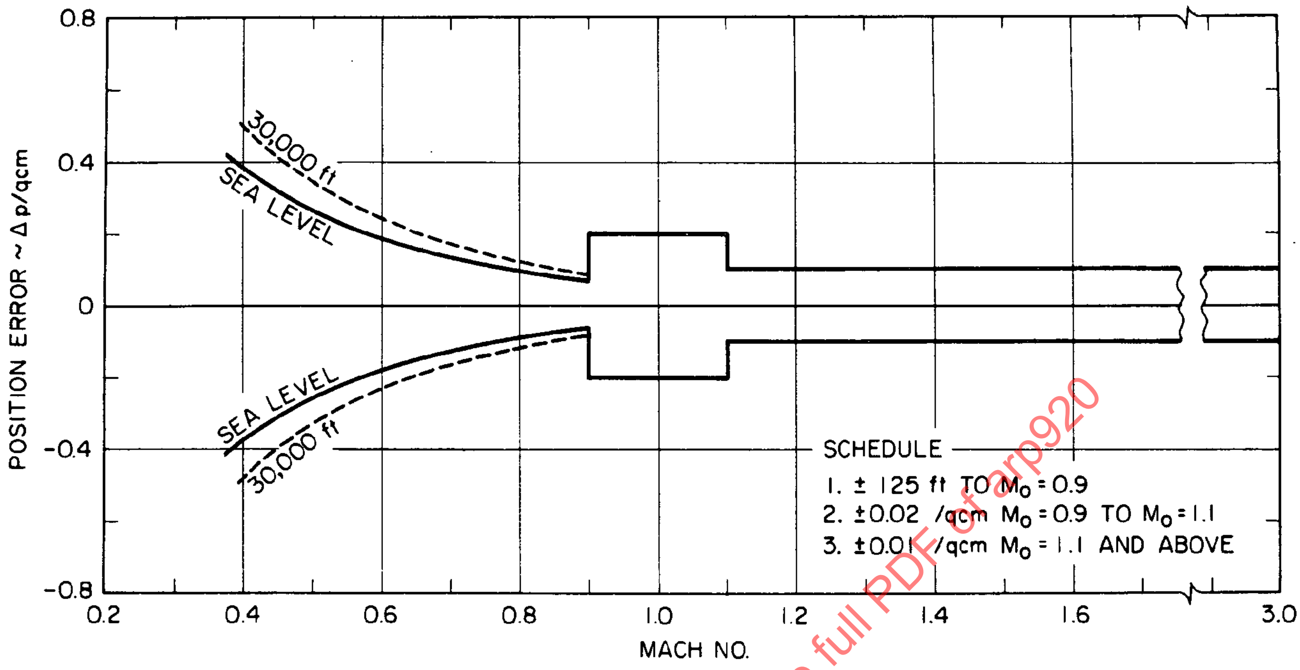

FIGURE 5 - STATIC POSITION ERROR SCHEDULE
ILLUSTRATED EXAMPLE

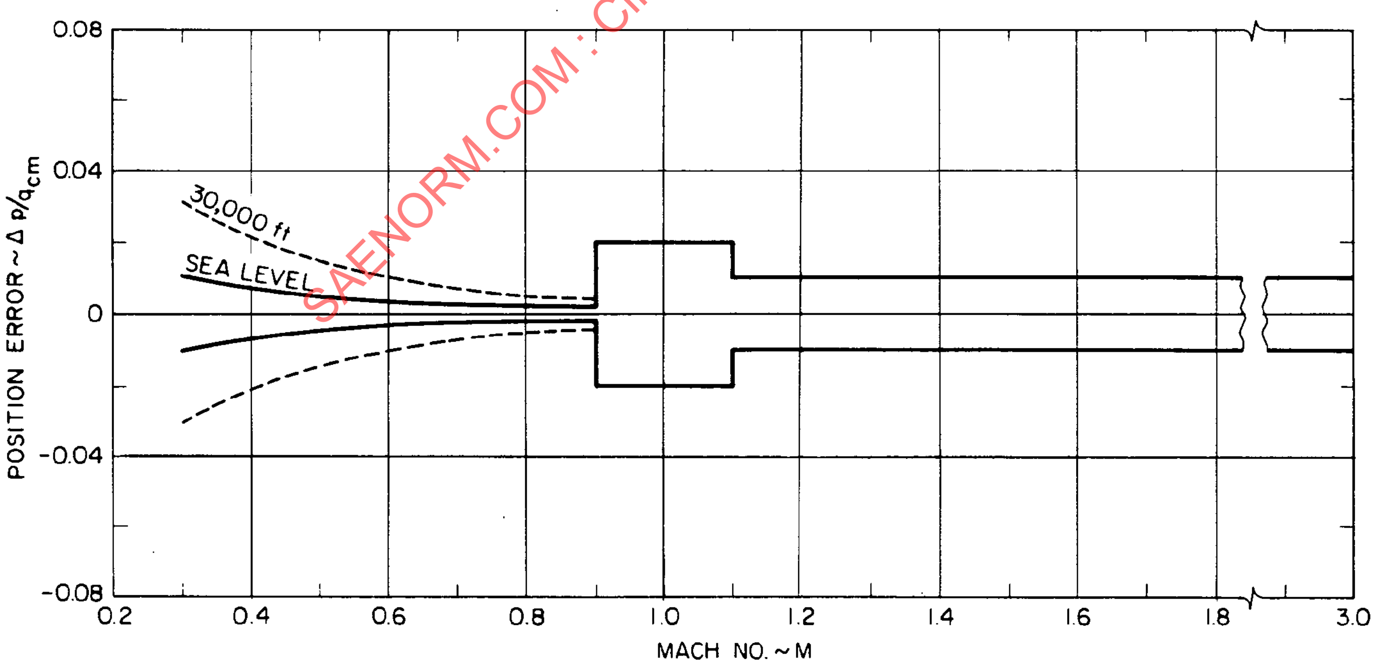

FIGURE 6 - STATIC POSITION ERROR SCHEDULE
VARIABLE AERODYNAMIC COMPENSATION

what more severe than that noted above. Precise measurement of altitude and airspeed is also necessary for efficient, economical operation of the aircraft. Therefore, static position errors should not exceed those specified herein and illustrated in Fig. 5 and 6.

(1) ± 25 ft or one quarter of one percent (.25%), whichever is greater, throughout the performance envelope of the aircraft up to a Mach number of 0.90 if compensated (see Fig. 6).

(2) ± 125 ft throughout the operating envelope of the aircraft if uncompensated (see Fig. 5).

(3) ± 0.20 $\Delta p/q_{cm}$ between a Mach number of 0.90 and a Mach number of 1.10 (uncompensated). ± 0.020 $\Delta p/q_{cm}$ if compensated.

(4) ± 0.010 $\Delta p/q_{cm}$ above a Mach number of 1.10.

The design goal for the gradient of position error should be equal to or less than:

(a) 1.5 knots per 10 knots of airspeed in the speed range between 1.2 V_S and V_{Fe}, with landing flaps.

(b) 50 ft per 0.025 Mach number up to M_{M_O} plus 0.01 Mach number.

NOTE: To accomplish the above accuracies, fixed aerodynamic compensation may be necessary and is permitted. See para. 4.5.2.2a(9) through 4.5.2.2a(11).

4.5.2.2 Captain, First Officer's and Auxiliary Static Sources

a. Flush Static Ports - If flush static ports are used, they should be paired and installed on each side of the aircraft symmetrically about the aircraft centerline and cross connected so as to eliminate the effects of aircraft yaw or sideslip (see Fig. 1 and 2). The cross-connected ports should be connected to the main static line at the approximate midpoint of the cross-connection.

(1) Static Port Installation - The flush port fitting should consist of a metal plate shaped to match the fuselage curvature, and approximately equivalent in rigidity on an aluminum alloy plate of .125 in. (3.17 mm) thickness. Within a radius of 3 in. (76.2 mm) of any orifice no part of the external surface of the plate should deviate from its design contour by more than ± .002 in. (.051 mm); beyond this radius the tolerance for departure from contour may be allowed to increase proportionately with radius to ± .020 in. (.51 mm) at the edge of the plate. The plate may be inset into the skin, or overlaid upon it. It should not be painted.

Skin Roughness - Skin roughness can be caused by poorly installed or unshaved rivets and screws and burring due to light impact with ground support equipment, etc. Small surface irregularities caused by slight depressions or elevations of rivets and screws will cause errors in static pressure up to as much as 1.0 percent. Therefore, the surface finish within an area of a 12 in. (304.8 mm) radius surrounding the static ports should be to 32 micron inch rms or better. The effect of burred and deburred screws installed within close proximity of the static orifices is shown in ARP 975. The importance of properly filling and smoothing screw heads is also shown in this recommended practice. It should be noted that it is not enough to just fill the holes and recesses, but the filling compound must then be smoothed off (see para. 4.5.2.2a(7).

(2) Static Port Mounting Plate Size - The static port mounting plate should be of such size that the distance from any set of orifices to the nearest edge of the plate should be the greater of the two alternatives listed below:

(a) The distance beyond which a step in contour or a step or bulge of 0.20 in. (5.08 mm) depth or height will have a negligible aerodynamic effect. This distance is generally considered to be a minimum of 80 times the height or depth of the discontinuity.

(b) The distance required to allow attachment of the plate to a circumferential frame, intercoastal or logitudinal stringer.

(3) Test Adaptor Mounting Holes - Above and below each set of orifice(s) there may be flush mounting provisions with threaded blind hole for the attachment of external pressure test fittings (adaptors). These threaded inserts should be present at the time of the flight calibration of the static system so that any effect they might have will be included in the calibration.

(4) Large Irregularities - Large irregularities are caused by skin laps, improperly adjusted cargo doors, radomes, etc. These irregularities will cause errors in airspeed if the distance between the disturbance and the static orifice, divided by the disturbance height, is more than 80 (see Appendix II).

(5) Grouping of Static Ports - The captain and copilot's static ports should be closely grouped together on each side of the aircraft on the assumption that their calibration will be essentially the same. Auxiliary static system ports may be grouped either with the primary or alternate system ports, or at some other "minimum error" location convenient to the system to which it is connected. The grouping of the static ports should be such that there is no interaction between them.

(6) Static Port Location - The location of the static ports should be such that they will be protected from meteorological conditions such as icing by virtue of being far enough aft and such that their calibration will not be affected by the rigging of doors, vent holes, etc. Drains and scuppers should not be located in such a manner as to allow water or other fluids to run over the ports either while the aircraft is on the ground or while it is airborne. The area chosen should have little or no angle-of-attack effect and should provide a low error repeatable static pressure.

(7) Static Orifice Fittings - The static orifice fittings (if separate from the mounting plate) should be made of non-corrosive material. The preferred configuration (Fig. 7) should aid in the exclusion of the insects or other foreign matter capable of obstructing the connecting tubing. The total area of the orifice(s) should

not be smaller than the cross-sectional area of the piping to which it is connected (para. 4.6.1).

If no static position error compensation is made by aerodynamic means (see para 4.5.2.2a(10)) then the face of the separate static orifice fittings (if used) should be flush with the surrounding skin or plate surface to within ± .001 in. (0.25 mm) (see Appendix II). The gap between the outside diameter of the static orifice fitting and the hole in the skin through which it protrudes should be completely filled with an appropriate compound and smoothed off such as to eliminate any discontinuity in the skin surface.

(8) Static Orifice Hole Condition - The internal surfaces of the holes should be clean and free from burrs. The outer edge of the hole should be free of burrs, raised edges or nicks.

(9) Static Port Identification - Adjacent to each set of orifices the system designation (i.e., captain, first officer's, alternate, etc.) should be etched or otherwise permanently marked at a distance equal to or greater than 6 in. from the nearest orifice. The markings should be shallow enough and/or of sufficient distance from the port so as not to violate the surface contour and smoothness requirements specified in para. 4.5.2.2(1). Such markings should not be located where they may impair the sealing of an external test fitting.

All flush static ports or groups of flush static ports should be enclosed with a bright red line approximately .375 in. (9.52 mm) in width. This line should have no appreciable thickness as would be the case if tape were used. In addition, the following legend should be placed above or below the red enclosure so as to be readily visible to a man standing on the ground along side the aircraft.

STATIC PORTS - DO NOT PLUG OR DEFORM HOLES.
AREA WITHIN RED LINE MUST BE SMOOTH, CLEAN
AND FREE OF ICE

The above legend should be in red letters at least .50 in. (12.7 mm) high.

(10) Contoured Plate Compensation - If a contoured plate is used, it should be sufficiently thick (0.125 in. - 3.00 mm) so as to prevent deformation of the critical contour due to aircraft aeroelasticity. It should be installed such as to avoid sharp edges and steps which would cause an undesirable airflow condition. No part of the plate should depart from the fuselage contour by more than .25 in. (6.35 mm) and no deformation from the designed curvature should be greater than that which will induce static position errors which would exceed the limits given in para. 4.5.2.1b.

(11) Static Port Fitting Compensation - Consideration may be given to the use of compensating devices which vary the aerodynamic characteristics of the static port either by a fixed compensation such as non-flush ports or contoured plates or by electro-mechanical means providing they can be shown to be sufficiently reliable, free from ice and fail-safe so as to insure against the occurrence of a hazardous condition. Examples of such compensating means are shown in Fig. 8 and 9.

When variable compensating means are used, the electro-mechanical design should be such that electrical power failure will cause the port to return to the uncompensated (neutral) position. It should also alert the flight crew of the occurrence of such power failure or malfunction.

The design objective of compensated flush static ports should be that, in addition to federal air regulations requirements for low speeds and altitudes, the error will

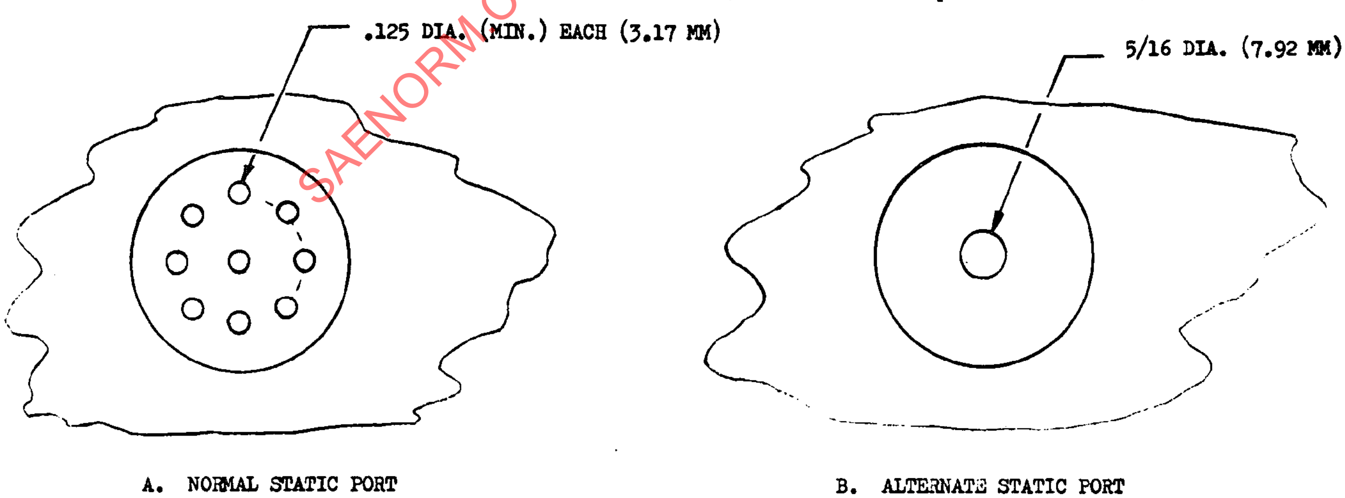

FIGURE 7 - NORMAL AND ALTERNATE FLUSH STATIC PORT CONFIGURATIONS

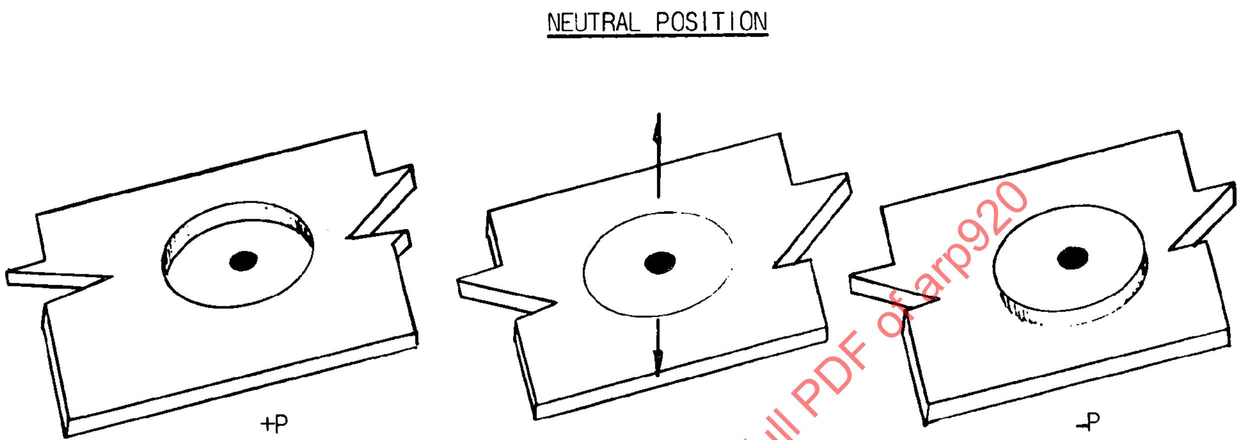

FIGURE 8

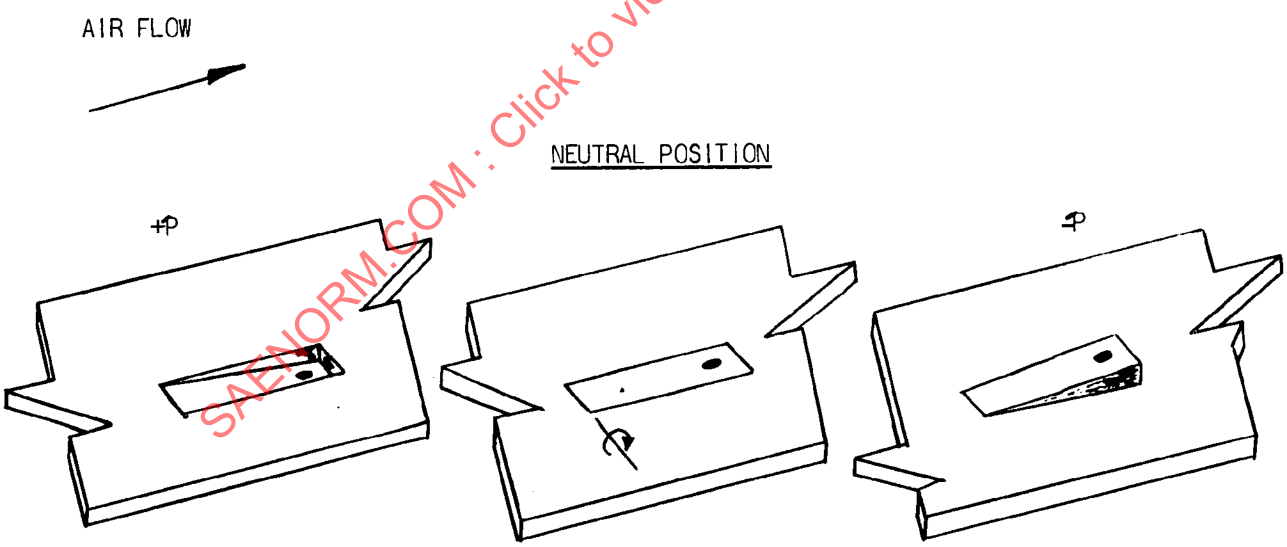

FIGURE 9

not exceed the limits of para. 4.5.2.1b at any normal aircraft configuration or altitude at speeds up to M_{mo} plus 0.10 Mach.

(12) Flush Static Port Anti-Icing/De-Icing - Should it be impossible to locate, the static ports such as to be free from the formation of ice, either from inclement weather or due to the flow water from drains or vents, then an anti-icing heater should be provided. Such heater should be mounted flush with the skin surface or on the internal surface and of such thermal capacity that, when activated, it will dissipate and/or prevent the formation of ice either on or in the immediate vicinity of the flush static ports.

(13) Ground Operation of Anti-Icing/De-Icing Heaters - Should such flush static port anti-icing/de-icing heaters be provided, they should be designed so that no damage to the static port(s) fitting or aircraft skin should result from allowing power to be applied to the heaters for a period of five hr at any one time while the aircraft is on the ground.

(14) Heater Power Monitoring - Should such static port anti-icing heater be provided, some means should be provided to indicate to the crew that electrical current, if used, is being used by the anti-icing/de-icing heaters.

b. Static Pressure Sensing Technique - The selection of the static pressure sensing technique to be used (i.e. pitot-static tube, flush static port) and their location (nose-mounted, wing-mounted, center fuselage, vertical stabilizer, etc.) should be based upon achieving the following characteristics (as listed in order of merit): repeatability, minimum gradients, and minimum errors.

(1) Static Pressure Tubes - Static pressure tubes may be used if they can be shown to have significantly lower errors than flush static ports. If used, such tubes or probes may be combined with the pitot (total) pressure tube.

(2) Nose-Mounted Static Tubes - If nose-mounted static tubes are used, their length, including the boom upon which they are mounted, should not be greater than one-quarter of the effective fuselage diameter.

(3) Wing-Mounted Static Tubes - If wing-mounted static tubes are used, their length, including the boom upon which they are mounted, should not be greater than one-quarter of the length of the wing chord at that location. In order to minimize the possibility of damage, the most outboard mounting location should be inboard of the wing tip a sufficient distance so that when the aircraft is turning while taxiing, the probe will be within the sweep of the wing tip. Probes should not be mounted directly on the wing tip.

(4) Static Probe Aerodynamics - If probes mounted on masts protruding from the fuselage are used, the mast length should be sufficient so that an adjacent skin dent or bulge of 0.30 in. (7.62 mm) depth or height will have negligible effect on the pressure sensing. Insofar as feasible, they should be so located as to minimize the probability of being inadvertently contacted by personnel or ground equipment.

(5) Static Probe Alignment - Static probe alignment restrictions are identical to those specified for pitot tubes. (See para. 4.5.1.3.a.)

(6) Static Probe Anti-Icing - Static probe anti-icing restrictions are identical to those specified for pitot tubes. (See para. 4.5.1.2.b and 4.5.1.2.c.)

c. Static System Calibration Data - The data upon which the final "approved" calibration of the static system for each aircraft model is based should be obtained from flight calibrations of at least three aircraft of the given type or model in accordance with ARP 921.

4.5.2.3 Alternate Static Source - The alternate static source may be a pair of flush ports mounted and connected in a manner similar to the captain and co-pilot's systems (see para. 4.5.2.2).

a. Location of Flush Type Alternate Static Source - As noted in para. 4.5.2.2a(5), when flush type static ports are used in the alternate static system, they should be located a distance of at least 5 ft (1.524 m) from the normal sources.

b. Alternate Static Source Error - The altitude error should not exceed ± 40 ft per 100 knots for the appropriate configuration in the range of 1.3 V_{so} to 1.8 V_{si} at maximum landing weight and configuration and -30 or +20 ft at any other speed, weight or configuration within the normal operating envelope of the airplane. The gradient of airspeed error should not exceed 1.5 knots per 10 knots of airspeed in the speed range 1.2 V_s to V_{fe} with landing flaps and 1.8 V_{si} with flaps retracted.

c. Pitot-Static Tube Static Pressure Orifices - The shape, size and location of the static pressure orifices of a pitot-static tube should be such as to minimize errors due to the airflow into and around the tube.

4.5.2.4 Auxiliary Static Systems

Cabin Pressure Control Static System - In aircraft equipped with cabin pressure controls of the type which require the bleeding of air from the cabin to static pressure, a separate static source should be provided (see paragraph 4.4.2.4). If such a separate static source is located close to the captain's, co-pilot's, alternate or other auxiliary sources, the ports should be located below and/or aft of them.

4.5.2.5 Static Source Calibration Data - The approved aircraft flight manual should include curves showing the calibration of each static pressure system. These calibration curves should be given in terms of altitude, airspeed and Mach number for all operating conditions and configurations.

Where any significant portion of the airspeed and Mach errors are chargeable to the pitot system, this should be so indicated.

4.6 Plumbing - The adequacy and integrity of the pitot and static system plumbing is nearly as important to the operation and reliability of these systems as is the sensing sources themselves. Therefore, considerable care and thought should be exercised in its design. The following recommendations should be adhered to whenever possible.

4.6.1 Tubing and Hose Sizes

4.6.1.1 Pitot Systems - The nominal size of tubing used in the design of pitot systems should be .3125 in. (7.925 mm).

4.6.1.2 Static Systems - The nominal size of tubing and hose used in the design of static systems should be .375 in. (9.525 mm).

4.6.1.3 Tubing Wall Thickness - The wall thickness of aluminum tubing should not be less than 0.028 in. (1.70 mm) or more than .035 in. (.925 mm). The wall thickness of stainless steel tubing should not be less than 0.016 in. (.41 mm) or more than .035 in. (.925mm).

As implied in para. 4.5.1.1 and 4.5.1.2 above, hoses (or at least their threaded fittings) joining system tubing to instruments should be of different sizes for pitot and static connections. The static system fittings should be larger than those used in the pitot systems.

4.6.1.4 Hoses - Flexible hose may be used between system tubing and the individual instruments connected thereto in order to facilitate their installation and to reduce the strain on the instrument which could result from misaligned rigid tubing. Such hose should be equal to or better than the AN6270 type. The use of hose reinforced with an internal wire coil and/or external plastic coil or wire wrap is strongly recommended.

Hose Routing - The hose should be of such length and routed in such a manner as to avoid the possibility of its kinking, pinching or stretching due to the operation of hinged panels, etc. Efforts should be made to standardize on hose lengths.

4.6.2 Fitting Types - Tubing joined to hoses which are in turn connected to instruments should be terminated in flared type fittings. Test fittings should also be of this type. Flareless type fittings should not be used in these applications.

A fixed fitting which is connected to a section of tubing or hose intended for routine removal and replacement should have an accessible wrenching hex or flat, or be mounted such that the wrenching torque on the removable section cannot be transmitted to an inaccessible section of plumbing beyond the fixed fitting.

4.6.3 Plumbing

4.6.3.1 Drainage - All tubing and hose, with the possible exception of that mounted to instruments on instrument panels, should slope away from the instrument toward drains or sumps. Where the entry of a pitot tube or a static port vent fitting is at the low point of a portion of the system, it may be considered as a drain.

NOTE: This requirement is more critical for spanwise routed lines than the fore and aft lines. Fore and aft lines are assisted in draining by the airplane pitch changes in climb and descent. Spanwise lines are not similarly assisted by roll motion, since in transport aircraft roll is usually avoided except as a part of coordinated turns.

The tubing connected to the pitot tube or static port fitting immediately inside the aircraft skin should rise as nearly vertical as possible for a distance of at least 18 in. (457.8 mm). Where the pitot or static tube is mounted above the structure upon which it is supported, the tubing should run downward to a sump located as closely to the tube as is practicable.

Where the pitot tube or static port is mounted on a section of pressurized and thermally insulated skin or bulkhead, the plumbing connected thereto should pass through the insulating blanket as close to the pitot tube or port as possible, thereby keeping as much of the plumbing as possible from freezing temperature.

4.6.3.2 Location of Drainage Provisions - A drain or capped fitting should be provided at the low point of each system or portion of a system. Unless the pitot tube or static port fitting is located at the lowest point of its respective system, a sump should be installed between the tube or fitting and the rest of the system. Where practicable, such installation should be in an easily accessible, unpressurized location. Long fore and aft lines may be exempted from this requirement if all of the following is met:

a. All parts of the line must be within two in. of the same distance from the horizontal reference plane.

b. All parts of the line must be within 2 deg of parallel to the reference plane.

c. There must be a drainage provision at the end.

4.6.3.3 Design of Selector Valves - The selector valve for switching the captain or first officer's instruments from normal to alternate static system should be of the make-before-break type: i.e., in mid-travel of the valve the instruments should be connected to both normal and alternate sources, rather than neither. It should also have an over center action such that it will not readily remain in mid-travel. The minimum cross-sectional area of the air passages should be no less than that of the tubing.

4.6.3.4 Design of Drain Valves - If drain valves are used and they are installed in unpressurized locations, they should be of the spring-loaded self-closing type. Where drain valves are installed in pressurized areas, they should be of such design that the cabin pressure does not oppose the spring in such a manner that tends to unseat the valve.

4.6.4 Plumbing Pneumatic Lag - The total lag in the pitot-static system plumbing should be kept to an absolute minimum consistent with the tubing diameters suggested in this recommended practice. The method for computing lag is provided in Appendix II.

4.6.5 Labeling - Tubing should be clearly labeled as to the system to which it belongs (i.e. captain's pitot, auxiliary static, etc.) within 12 in. (304.8 mm) of each end, or as close to the end as possible in the event the labeling may be obscured by the installation. If arbitrary number or letter run designations are used, they should be in addition to, not instead of, the previously noted means of identification.

In protected areas, pressure-sensitive adhesive tape bands or ink stamping should be adequate. If color coding is included, it should be in accordance with MIL-STD-1247.

Tubing or hoses connected to static system selector valves should be labeled "normal", "alternate", and "instruments" to agree with the identification of the selector valve, unless the physical arrangement is such as to prevent accidental misconnection.

Drain and test fittings should be durable labeled as to which system each is connected. In wheel well areas, the labels should be resistant to water and hydraulic fluids.

4.6.6 Thread Sealing Material - Thread sealing or lubricating material, when used, should be of the paste type. Plastic type tapes should not be used.

APPENDIX I

References:

Anderson, O. E. E.	Recommendation of Design of Pitot-Static Systems for Transport Aircraft (United Airlines Report F-823B dated 3 July 1963).
Air Transport Association	Recommendations on Design of Pitot-Static Systems for Transport Aircraft, January 1964.
Air Transport Association	Recommendations of Flush Static Port Maintenance, December 1963.
Gracy, William	The Measurement of Pressure Altitude on Aircraft (NASA TN-4127) October 1957.
Deleo, R. V. Hagen, F. W. Kooiman, R. R. Thompson, D. I.	Evaluation of Factors Affecting Accuracy of Aircraft Static Pressure Systems (SEG-TR-65-35, dated July 1965).
Silsby, N. W. and Stickle, J. W.	Flight Calibrations of Fuselage Static Pressure Vent Installations for Three Types of Transports (NASA TN-D-1356) May 1962.
Stratton, D. W.	The Effects of Installation Irregularities on Flush Static Systems and the Means of Eliminating Them.
Stratton, D. W.	Effects and Control of Installation Irregularities on Flush Static Systems (Douglas Air. Report #LB-30765 dated December 1961).
Stratton, D. W.	Static Position Error Compensating System - Its Theory and Design Details (Douglas Air. Report SM-41532 dated March 1962).
Wheatley, J. L.	Relation of Static System Leakage to Altitude Error (United Airlines Report F-1096, dated April 22, 1966).

Definition of Symbols:

V	FAA Certified Aircraft Stall Speed (Indicated Airspeed)
V_{fe}	FAA Certified Aircraft Maximum Airspeed (Indicated) with Flaps Extended
V_{so}	Calibrated Stalling Speed or Minimum Safe Speed at Which Aircraft is Controllable
V_{si}	Indicated Stalling Speed
ΔP	Pressure Differential between True Ambient Barometric Pressure and the Barometric Pressure at the Aircraft Static Port
q	Impact Pressure (Lbs/Ft^2)
q_{cm}	Measured Dynamic Pressure
M	Mach Number
M_{mo}	Maximum Operating Limit Mach Number
C_p	Pressure Coefficient
V_o	Airspeed at Orifice Location (Lbs/Ft^2)
ρ	Air Density

APPENDIX II

1. INTRODUCTION

The purpose of this appendix is to provide the user of ARP 920 with certain explanatory information and formulas which are necessary in the design of pitot-static systems, but which are not readily available. The data presented in this appendix is not intended to be all-inclusive, but to act only as a guide to be used as appropriate.

2. STATIC PRESSURE SYSTEMS

2.1 General Discussion

Since atmospheric pressure naturally and universally varies inversely with altitude above mean sea level, its measurement is used to determine the height above mean sea level that an aircraft is flying. However, since atmospheric pressure varies with air density, any object or phenomenon which tends to modify the local density or temperature of the air will cause a corresponding change in local atmospheric pressure. Thus, the motion of an aircraft through the atmosphere will change the air density and/or temperature and the corresponding atmospheric pressure surrounding most of the aircraft. It is for this reason that true pressure altitude (the measurement of true atmospheric pressure) is difficult to measure from a moving aircraft. Static pressure is therefore defined as the true atmospheric pressure as measured at some point on the aircraft where the pressure is unaffected by the presence or motion of the aircraft. Pressure altitude is the measurement of static pressure converted to feet above and below mean sea level.

One of the most difficult problems in designing a static pressure sensing system is that of locating the static pressure sensing source (tube or vent) on the aircraft. Since each aircraft design is unique, it follows that the (air) flow field around each aircraft is also unique. In addition, every effort is made in the design of each aircraft to obtain the highest degree of aerodynamic efficiency possible. Therefore, it becomes extremely difficult to find a location on or close to an aircraft where the static pressure can be detected without error under all flight conditions and variations in aircraft geometry. The problem then becomes one of determining a location and design for the static sensing source (tube or vent) where the errors are minimized or where they vary uniformly with Mach number, angle of attack, etc. Generally speaking, the region of the aircraft fuselage where the static sensing source can be most frequently and suitably located is approximately half way between the fuselage nose and the wing leading edge, and in the circumferential band between 25 and 45 degrees up from the bottom centerline. Extending beyond this circumferential band may result in the need for angle of attack correction by the use of an airflow direction detector.

Theoretically, the greater the distance from the aircraft that the static source can be located (preferably ahead of the aircraft), the more likely the chances are of minimizing the position errors. However, the use of booms, etc., is impractical for commercial aircraft for many reasons.

Therefore, most transport type aircraft now in use measure static pressure by means of orifices or ports mounted flush with the fuselage skin in the location previously noted. Flush static ports are generally used throughout the transport industry primarily because they create less drag than pitot/static probes and they are less subject to damage and the accumulation of ice under adverse weather conditions. In this type of installation it has been found that, in addition to position error, there is considerable scatter in the calibration data of the system for any one aircraft, and even more from one aircraft to another of the same type. Much of this aircraft-to-aircraft scatter has been correlated with variations in the contour of the skin at or near the ports; some of the errors may be attributed to the residual errors of the various methods of system calibration (Reference ARP 921). Departures from the original contour may become more pronounced as an aircraft gets older due to metal fatigue, accumulated damage, repairs, etc.

In discussing position errors, it is convenient to use basic aerodynamic parameters. Those of major concern are the static pressure coefficient ($\Delta p/q$), boundary layer thickness, aircraft angle of attack (α) and Mach number (M). Changes in aircraft geometry should also be given serious consideration.

The effect of position error on various key flight instruments can be roughly approximated by the following equations:

Altimeter: $dh \doteq 16,500 \times M^2 (\Delta p/q)$, ft (1)

Rate of Climb: Negligible Error

Airspeed Indicator: $dV \doteq 1/2V (\Delta p/q)$, knots (2)

Mach Meter: $dM \doteq 1/2M (\Delta p/q)$ (3)

True Outside Air Temperature $dt \doteq -0.3\, TM\, (dM) = 0.15TM^2 (\Delta p/q)$ °K (4)

For current high speed executive and transport type aircraft there are two distinct operational flight regimes that affect static source pressure characteristics:

A. Low Speed Regimes - Compressibility effects (i.e., due to high Mach number) can be ignored. However, large variations in angle of attack (α) and flap deflections (δ) occur in this regime. Consequently, their effects on sensed static pressure cannot be ignored.

B. High Speed Regime - Compressibility effects predominate in the high speed regime. Angle of attack variations become relatively small and flaps are never intentionally deflected.

Referring to the approximation equations noted above, it should be noted that they are all proportional to $(\Delta p/q)$. Furthermore, these equations become more exact as $(\Delta p/q)$ approaches zero; the position error also diminishes to zero.

These considerations should be carefully kept in mind during the succeeding discussion on static position error compensation.

2.2 Static Port Installation

2.2.1 Skin Waviness - Skin waviness in the region of the static orifices will cause an error in static pressure, the magnitude of which is a function of the degree of skin deflection. Tests indicate that a wave where the ratio $\lambda/h = 80$ (Fig. 1) causes an error in the order of 0.40% in static pressure. Where the ratio is less than 80, the error is correspondingly greater.

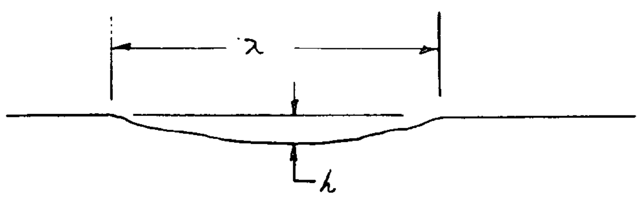

FIG. 1 - GEOMETRY OF SKIN WAVINESS

2.2.2 Large Skin Irregularities - Large skin irregularities are caused by skin laps, improperly adjusted cargo doors, radome mismatch, etc. These irregularities cause errors in airspeed and altitude if the distance between the disturbance and the static orifice, divided by the disturbance height, is more than 15 (see Fig. 2). However, this does not imply that offsets or laps of 1/2 in. (12.7 mm) are permissible so long as the requirements of the formulae are met. Such offsets and/or laps should never exceed 0.30 in. (7.62 mm).

2.2.3 Static Orifice Fitting Installation - If the static orifice fitting is a separate fitting from the immediately adjacent surrounding skin, any discontinuity between the surface of the fitting and the skin can cause errors in static pressure (see Fig. 3). Therefore, the face of such separate static orifice fitting should be flush with the surrounding skin or plate surface to within the tolerances specified in paragraph 4.5.2.2a(7) of ARP 920.

2.3 Aerodynamic Compensation - Aerodynamic position error compensation should be used in lieu of air data computers wherever possible, since such means tend to eliminate the static source at its source rather than compensating for the built-in error. It is recognized that there are cases and functions which are sufficiently complex that air data computers offer the only practical solution. However, initial consideration should be given to aerodynamic compensation.

Aerodynamic compensation may be accomplished by the addition of contoured plates and/or fences upstream of the static ports, or by variations in the static port fitting design and mechanization.

3. PITOT-STATIC SYSTEM LAG

The amount of lag in the pitot-static system is a critical factor in the design of such systems. Too much volume in a static system (either due to excessively large or long lines or too many instruments attached thereto) can cause system lag of such magnitude as to make the readout of instruments attached thereto dangerously erroneous. Therefore, the designer should exercise a complete lag analysis on each pitot and static system. In order that some consistency is maintained in the means by which system lag is computed, the U. S. Air Force equations are included below as the recommended formulation to be used.

3.1 Lag Equations

3.2 The Basic System - To treat the most generalized case of pressure lag error - including the interaction of those influencing parameters discussed in para. 3.3 - would require an analysis of such rigor and complexity as to render it impractical. Hence, as in many other problems, it is necessary to resort to simplified approaches which lend themselves to analytical treatment, but which at the same time furnish information of value concerning the real and more complicated situation.

A simple pressure-measuring system consisting of a single length of uniform tubing connected to an instrument will now be examined. Such an arrangement is shown in Fig. 4.

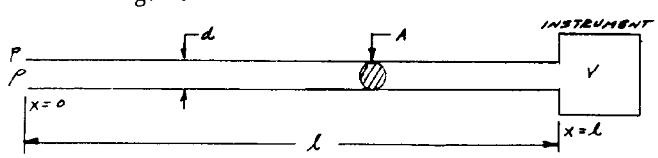

FIG. 4 - THE BASIC SYSTEM

The following assumptions will be made in the analysis:

(1) incompressible fluid,
(2) one-dimensional steady flow,
(3) laminar frictional values,
(4) isothermal fluid conditions, and
(5) ramp forcing function.

Three fundamental principles will serve as the basis for the development of an equation for the pressure drop due to friction in this system:

(1) Navier-Stokes equation (equation of motion),
(2) equation of state, and
(3) equation of continuity.

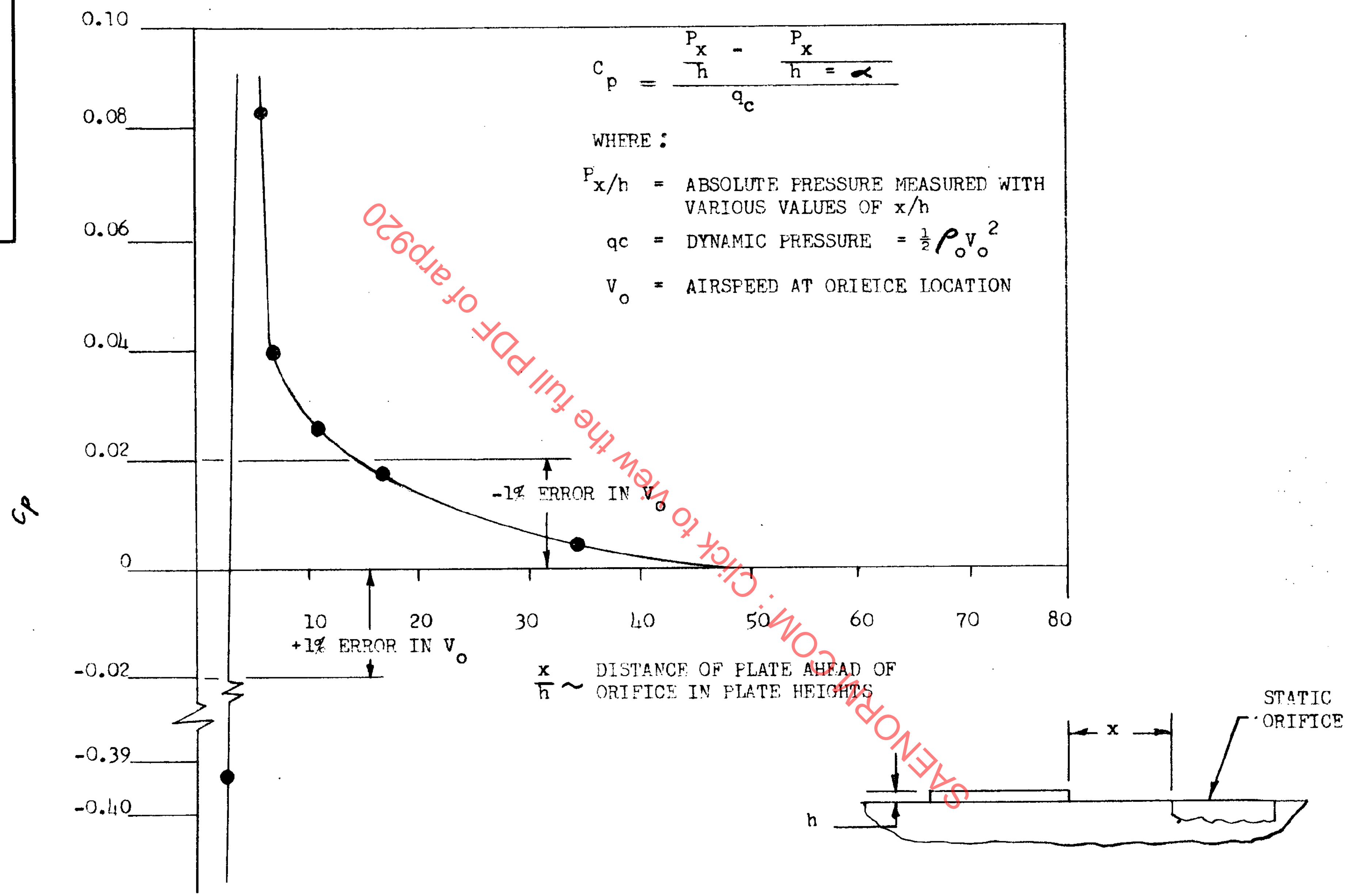

FIGURE 2 - TYPICAL CURVE OF EFFECT OF FLOW DISTURBANCE ON STATIC PRESSURE COEFFICIENT

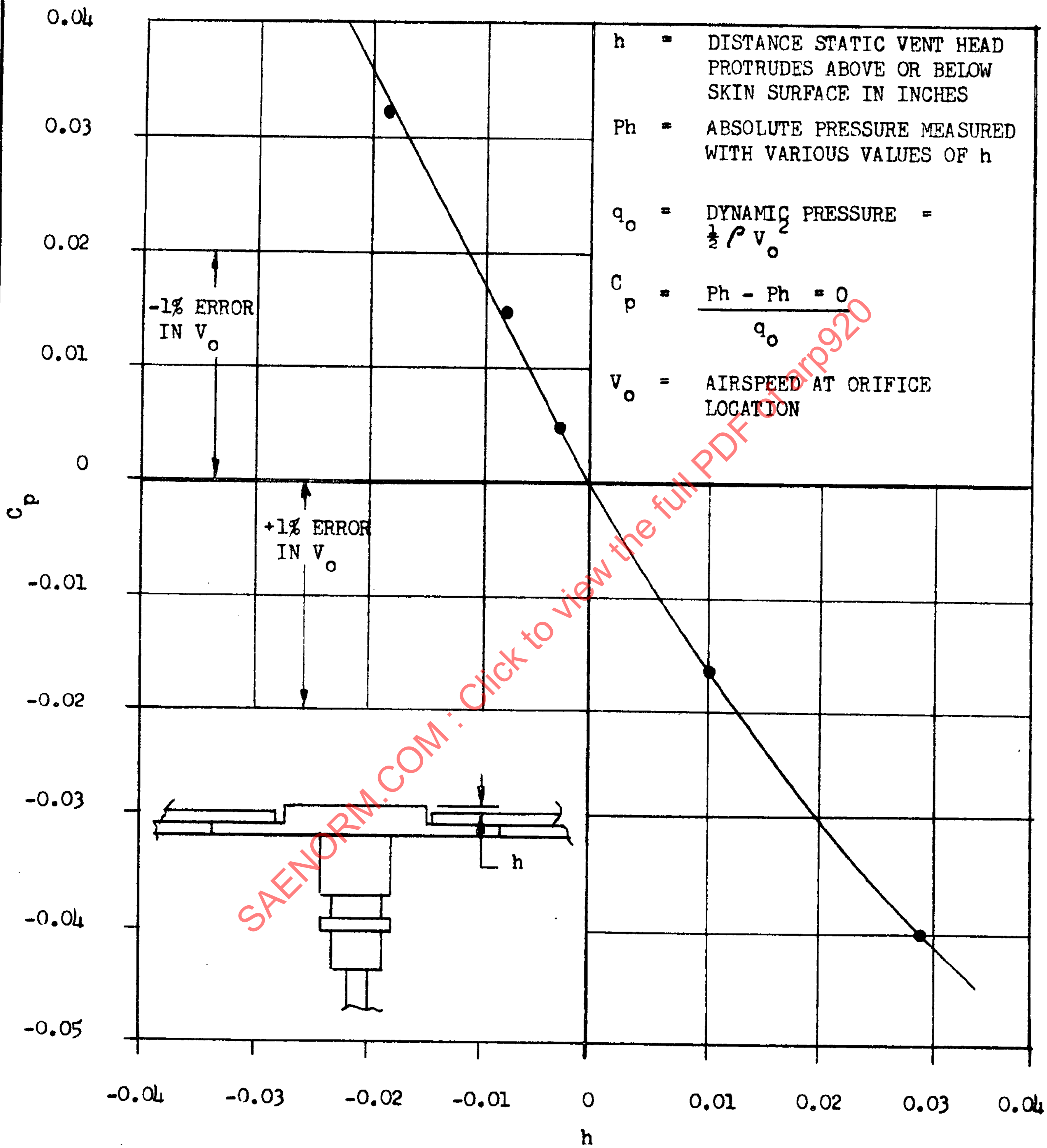

FIGURE 3 - TYPICAL CURVE OF EFFECT OF ORIFICE PROTRUSION ON STATIC PRESSURE COEFFICIENT