Docket No. SA-525

Exhibit No. #9A

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Systems Group Chairperson's Exhibit pertaining to
Airspeed, Attitude, and Stall Protection System (SPS)

(25 Pages)

Information from the

Canadair Regional Jet Series 100/200 Airframe/Engine Maintenance Training Manual:

The following pages pertain to the stall protection system and are taken from the Canadair Regional Jet Series 100/200 Airframe/Engine Maintenance Training Manual:

STALL PROTECTION SYSTEM

GENERAL

The Stall Protection System (SPS) provides the crew with warnings when the aircraft is approaching an impending stall condition.

The SPS also provides protection against actual stalls by means of a stick pusher.

Stall warnings are indicated by the following:

- Auto-ignition
- Stick shaker
- Autopilot disconnect
- Aural warning (warbler tone)
- Red STALL PUSH lights (on the glareshield)

In the event stall warning is not corrected and the stall margin decreases further, the control columns will be subject to a forward push from a stick pusher assembly.

Failure of the stall protection system is indicated on EICAS as a message.

COMPONENT DESCRIPTION

Refer to Figure 25.

AOA TRANSDUCER

Each AOA transducer includes an externally attached trailing vane assembly that connects to dual resolvers. The signal from the left AOA transducer is transmitted to the left channel of the SPS computer and the right signal is transmitted to the right channel.

Integral heater elements are installed in the trailing vane assembly to prevent ice buildup.

SPS COMPUTER

The SPS computer is installed in the main avionics compartment on the right avionics rack.

The stall protection computer is divided into two independent halves, channel 1 and channel 2. Separate AOA vane, flap position, lateral acceleration, Mach (from the Mach transducers and the digital air data computer) reset switch and Weight-on-Wheels (WOW) inputs are supplied to each channel of the computer.

The SPS computer uses the inputs from the Mach transducers, AOA transducers, and from the flap position transmitters to calculate the aircraft AOA and the actual stall speed.

The SPS computer uses lateral acceleration inputs from the attitude heading reference system (AHRS) to correct the AOA transducer inputs. These corrections compensate for the effects of maneuvers such as sideslips.

The SPS does not operate the stick pusher unless both channels of the computer send for a stick push within 3.5 seconds of each other.

As soon as the WOW signals are removed, the SPS computer starts to compute the AOA threshold based on Mach and flap position.

RESET SWITCH

This switch is located near the stall protection computer. Pushing this switch causes any stall protection system error indications on the EICAS to be removed from the system memory once the associated problem has been rectified.

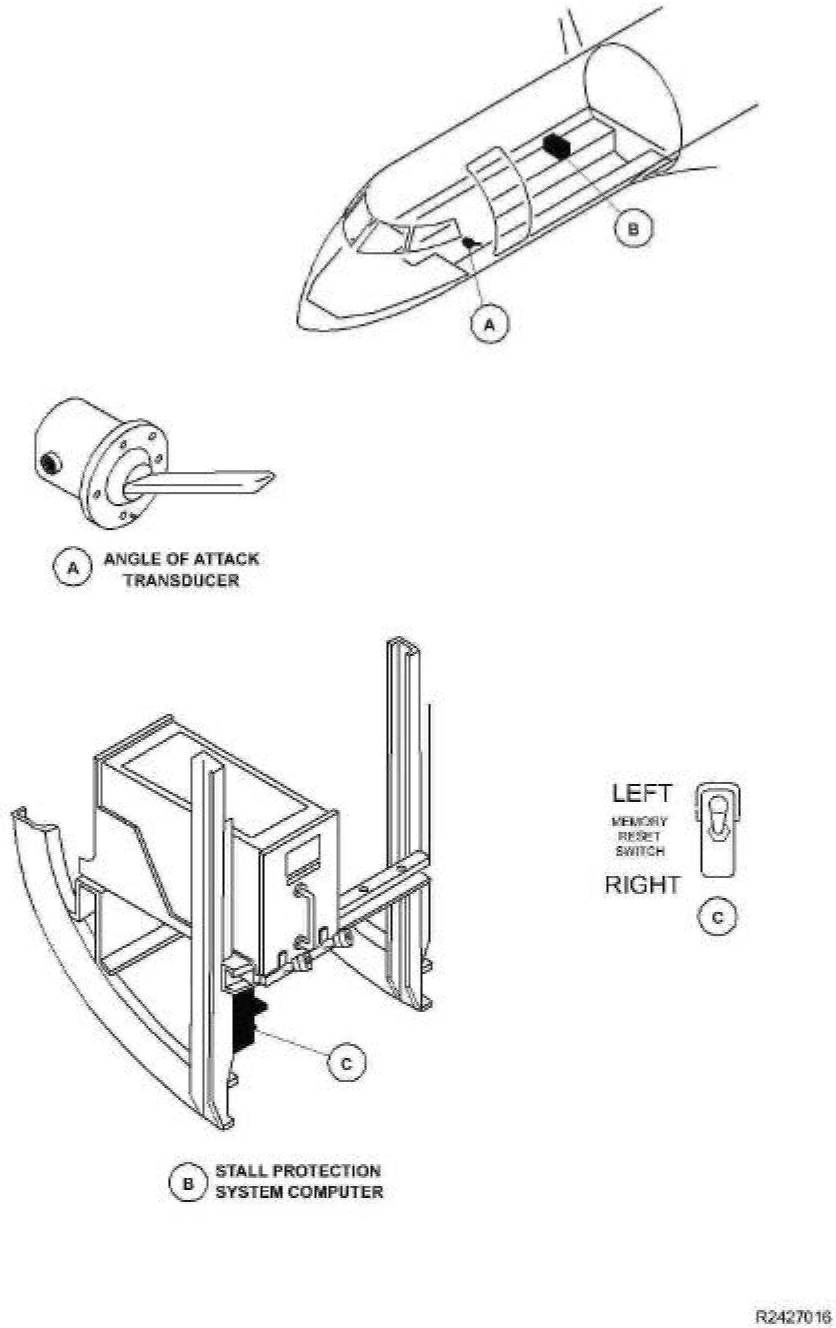


Figure 25 - Stall Protection System Component

STICK SHAKER UNIT

Refer to Figure 27.

The stick shaker units are installed on the forward side of the pilot's and the copilot's control columns.

Each stick shaker unit contains a 28 volts dc electric motor that operates an eccentric weight. The stick shaker vibrates the control column to warn the flight crew of an impending stall condition.

Each stick shaker unit operates independently and is powered by the respective SPC channel.

STICK PUSHER ASSEMBLY

Refer to Figure 27.

The stick pusher assembly is installed near the right elevator forward quadrant, below the cockpit floor.

The function of the stick pusher assembly is to push the elevator control column forward to correct a stall condition. The stick pusher assembly includes the following components:

- A stick pusher rotary actuator
- A stick pusher capstan
- An electronic control unit

The stick-pusher rotary actuator includes the following units:

- A 28 volts dc electric motor
- A gearbox
- An electromagnetic clutch
- A torque limiter (which contains mechanical slip clutches)

The stick pusher capstan is a pulley that transmits the movement of the stick-pusher rotary actuator to the elevator quadrant by a cable. The motor is electrically torque limited to 70 inch pounds to allow the pilot to overcome the force produced by the actuator to the control column. A back-up torque limiter is also provided by the capstan (SLIP CLUTCH) assembly to limit the force to a nominal force of 80 pounds on the control column.

The pusher actuator has been designed such that no single failure could result in the activation of the motor and the electromagnetic clutch. (Two improbable failures are required to cause nuisance activation of pusher sub-system.)

The electronic control unit contains failure monitoring and system logic circuits that supply the STALL FAIL indication to the pilot and copilot.

STICK PUSHER ON/OFF SWITCH

The switches are installed on the pilot's and copilot's side panels and are identified as STALL PTCT PUSHER ON/OFF.

Each stick pusher ON/OFF switch disconnects the 28 volts dc bus from the stick pusher rotary actuator. Each switch connects in series to the 28V DC BATT BUS from the stick pusher rotary actuator.

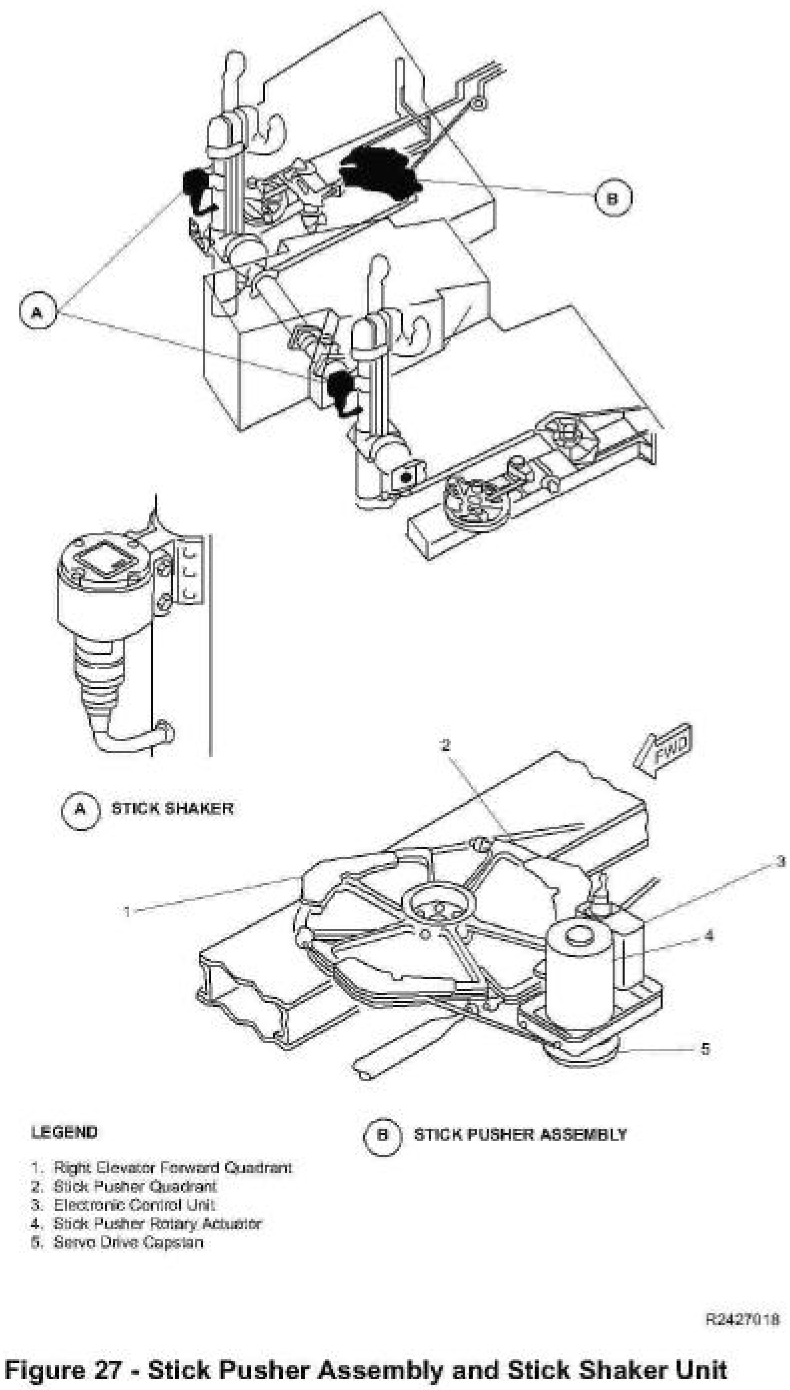


Figure 27 - Stick Pusher Assembly and Stick Shaker Unit

OPERATION INDICATION

The signals from the left and right angle-of-attack transducers are transmitted to the respective left and right channels of the SPS computer. Here they combine with imputs from lateral accelerometers (sideslip or skid) to give a computed angle-of-attack.

Mach transducers 1 and 2 supply primary Mach data to the respective channels of the SPS computer. Air data computers 1 and 2 supply secondary Mach data to the respective channels of the SPS computer. When the aircraft is airborne, the SPS computer monitors the AOA transducer, Mach, and other related data (flap position and AHRS/IRS) to determine the stall protection system AOA trip points.

As the aircraft AOA increases to the first (auto-ignition) trip point, each of the SPS channels sends an independent electrical signal to energize a relay in the engine ignition control circuits. This relay then energizes the circuits for the ignition A and ignition B igniters on each engine, and the ignition lights illuminates. This auto-ignition operation is a precaution against engine flameout during very high aircraft AOA.

As the aircraft AOA increases to the second (stick shaker) trip point, each SPS channel sends an electrical signal to its associated stick shaker unit. This causes the stick shaker units to vibrate the pilot's and copilot's control columns. If the autopilot is engaged when either one of the computer channels commands the operation of a stick shaker unit, then that SPC channel sends an electrical signal to the autopilot to disengage.

As the aircraft AOA increases to the third (stick pusher) trip point, each SPS channel sends appropriate electrical signals that cause the stall warning horn to sound (a warbler) and the pilot's and copilot's red STALL warning lights to illuminate. These events occur when either channel of the SPS computer detects that the aircraft AOA has increased to the stick pusher trip point.

In addition, each channel of the computer must send an electrical signal to the stick pusher rotary actuator within 3.5 seconds. These two signals are both routed through the electronic control unit to the rotary actuator. One of the two signals energizes the solenoid of the electromagnetic clutch and the other one drives the motor.

The operation of the electromagnetic clutch limits the torque produced by the rotary actuator to 70 inch-pounds. When the electromagnetic clutch is energized, the stick pusher rotary actuator sends an output through a gearbox to a torque limiter. The rotary actuator produces a forward stick push that is equivalent to 80 lbs of pilot force. The mechanical slip clutches in the torque limiter and in the stick pusher capstan act as a breakaway backups to the electromagnetic clutch if the later fails to release.

Refer to Figure 30.

The stick pusher and autopilot system can be disconnected temporarily by operating the AP/SP DISC button located on the outboard horn of each control wheel. The stick pusher system engages again immediately after the button is released.

There is an interface between the flap system and the stall protection system. The SPS computer uses the largest flap extension (a flap position of 45 degrees) as the flap position in the conditions that follow:

- If the position inputs from one of the flap position transmitters are lost.
- If there is a difference between the two flap position inputs, the SPS computer will increase the input it receives from the lowest input to the next flap position setting (45 degrees).

Thus, in the above conditions, the auto-ignition, stick shaker, and stick pusher trip points are reached at lower aircraft AOA.

Information from the

Pinnacle Airlines Flight Crew Operating Manual:

The following pages pertain to airspeed and attitude indication and are taken from the Pinnacle Airlines Flight Crew Operating Manual:

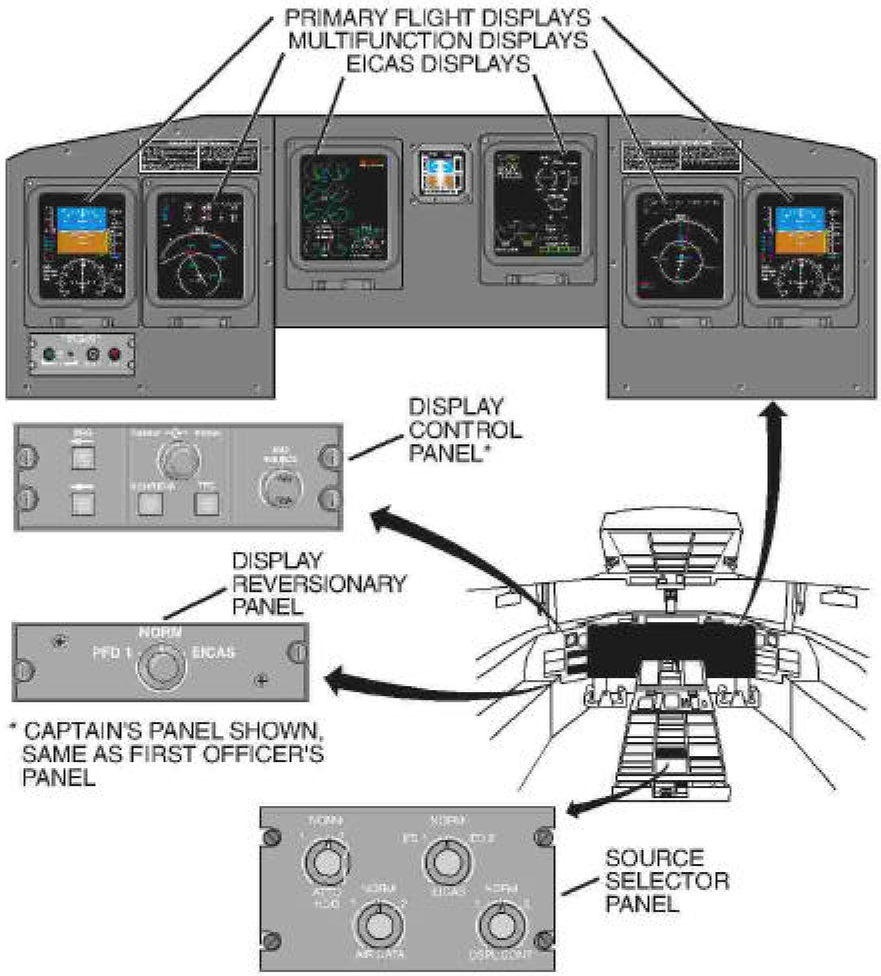


Figure 1-47 Flight Instruments

SYSTEMS DESCRIPTION

PITOT-STATIC SYSTEM

The pitot-static system consists of captain, first officer, and alternate subsystems. The captain and first officer systems monitor ram-air pressure and static pressure from dedicated pitot-static masts on the respective side of the forward fuselage (Figure 11-1). Each pilot system also provides air data inputs to the respective air data computer (ADC) and Mach transducer (Figure 11-2).

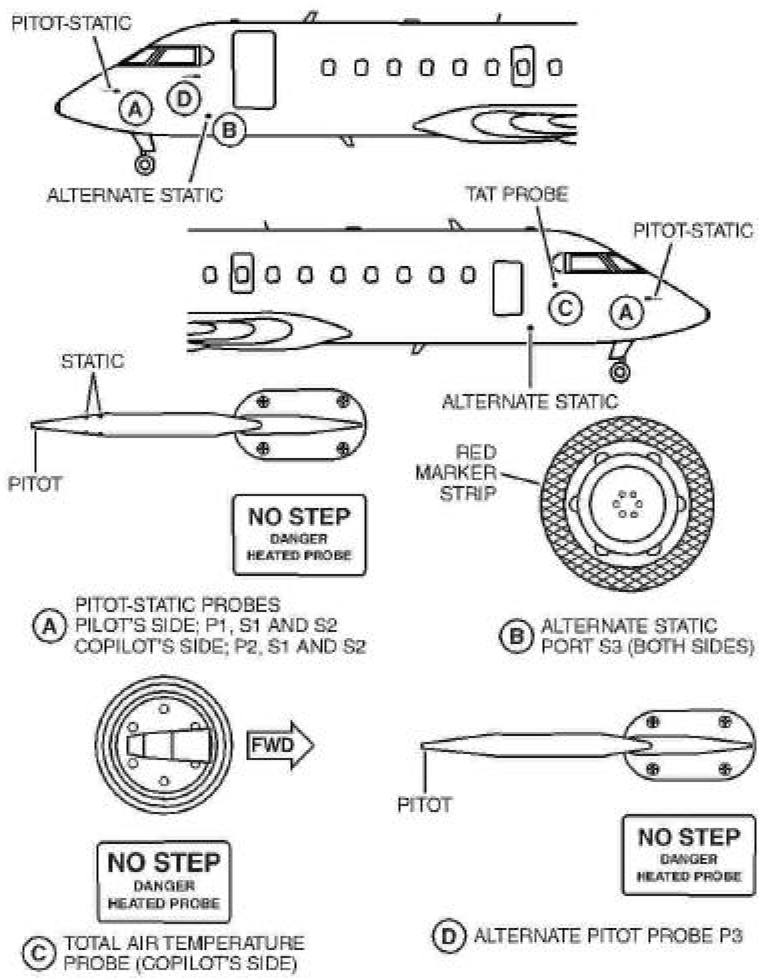


Figure 11-1 Air Data Probes

NOTE

Airspeed indication requires static pressure.

The alternate pitot-static system consists of a single pitot mast, on the left forward fuselage, and a static port on each side of the forward fuselage. The alternate system provides air data inputs to the integrated standby instrument system (ISIS) and to the cabin pressure acquisition module (CPAM).

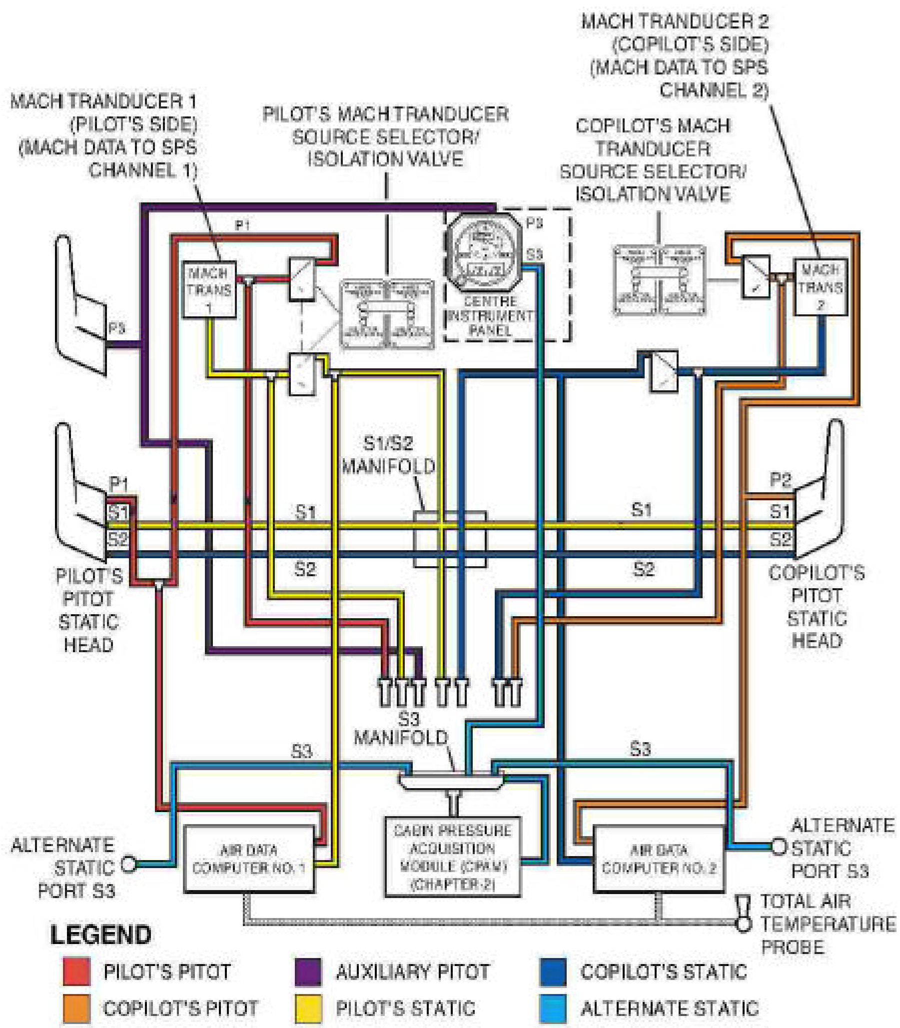


Figure 11-2 Air Data System

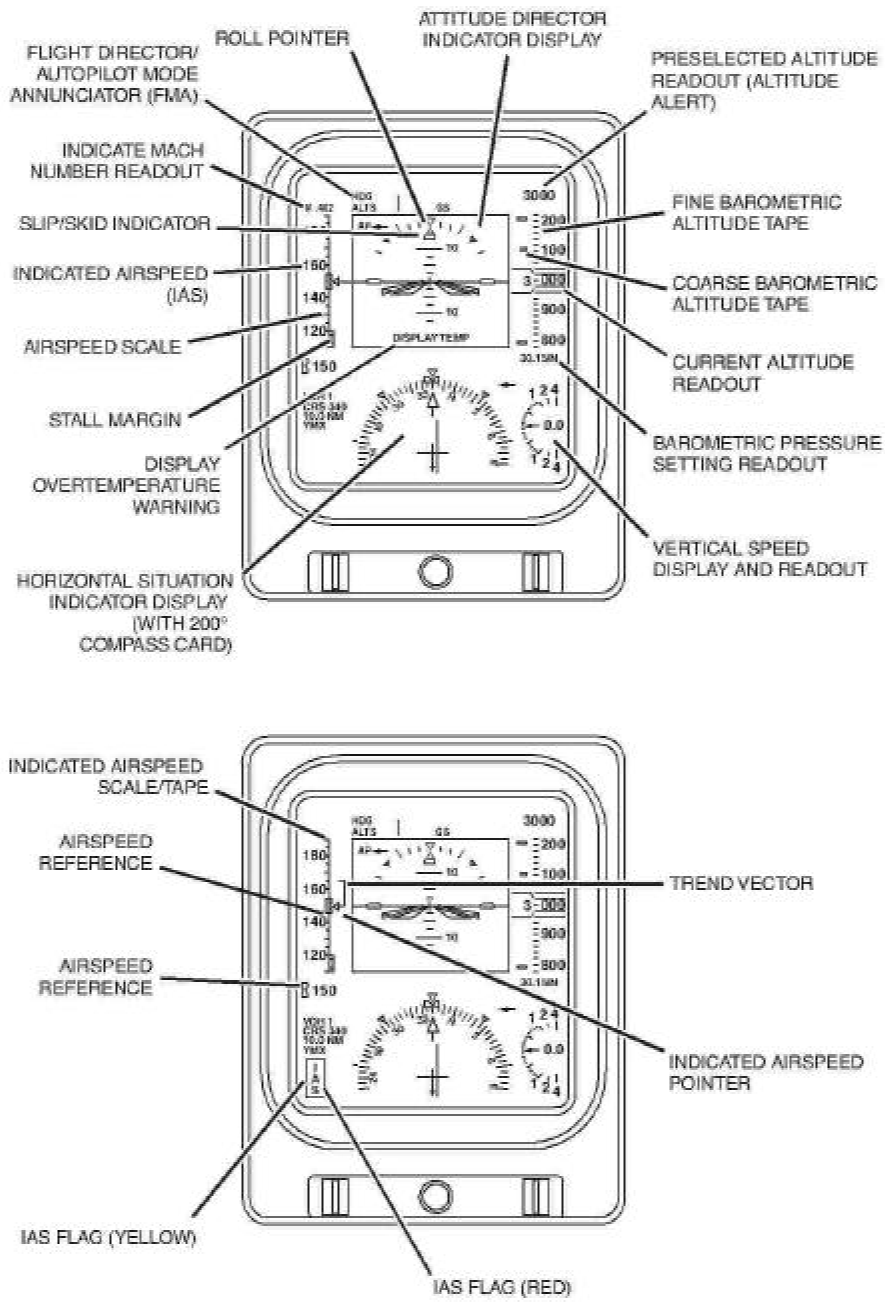


Figure 11-13 PFD Flight Display Symbols

IAS Flag

The yellow IAS flag appears when a mismatch (10-knots or more) is detected between airspeed data. The indication is accompanied by the yellow EFIS COMP MON message on the right side of the airspeed tape.

A red flag appears in place of the airspeed tape (scale and tape are removed) when airspeed data has failed.

Indicated Airspeed Pointer

This white pointer shows the indicated airspeed on the scale (always in view). The pointer is fixed in position.

Trend Indicator

This magenta pointer indicates the predicted airspeed in the next 10 seconds.

Indicated Airspeed Scale/Tape

This tape moves against a fixed pointer to indicate the current airspeed. Tape ranges from 30 to 400 knots with 80 knots in view at all times. The tape is marked as follows:

Airspeed from 30 to 200 knots:

- Tick marks each five knots
- Digits at 20 knots

Airspeed above 200 knots:

- Tick marks at each 10 knots
- Digits at 20 knots

PFD AIRSPEED INDICATIONS

Airspeed related symbols are depicted in Figure 11-14.

Indicated Mach Readout

Mach is indicated to the nearest hundredth at and above 0.45M when speed is increasing, Mach is inhibited below 0.40 when speed is decreasing or when Mach input is lost or failed.

Speed Reference Table

V_1, V_2, V_R, and V_T speeds are displayed in cyan when aircraft speed is less than 40 KIAS. These speeds are set by the SPEEDS REFS knob on the air data reference panel.

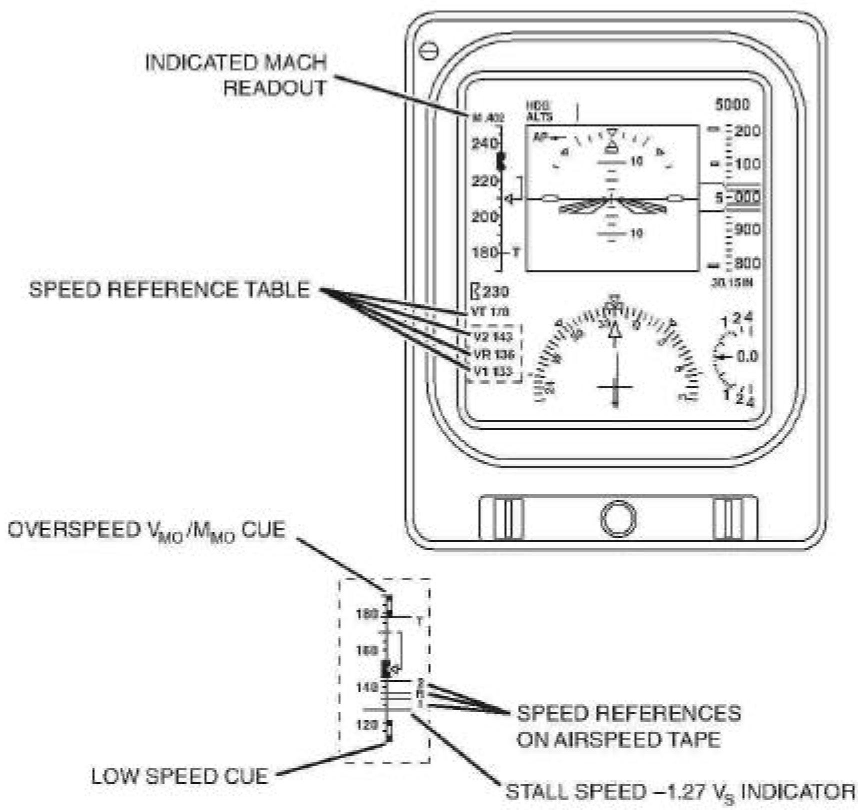


Figure 11-14 PFD Airspeed Indications

Overspeed V_{MO}/M_{MO} Indicator

This red/black checkerboard display moves up and down the tape to indicate maximum allowable speed. The overspeed indicator is generated by the air data computer and accompanied by an audible clacker.

Low Speed Indicator

This symbol appears three seconds after lift-off, and extends from the stall speed to the bottom of the tape. It indicates proximity to impending stall. If AOA data has failed, the low speed indicator changes to a yellow bar bracketing the lowest and highest stall speeds of the airplane.

Airspeed Tape Speed References

These cyan indications are displayed above 40 KIAS. After takeoff, the V_1, V_R, and V_2 bugs are disabled.

Stall Speed–1.27 V_S Indicator

This green bar indicates 1.27 times the AOA-calculated stall speed. The bar provides a visual indication of the current margin above stick shaker activation for any flap/weight combination.

NOTE

This green bar is not the approach reference speed. The V_{REF} data must be used to maintain adequate safety and performance margins.

PFD Attitude Indications

PFD attitude indications are shown in Figure 11-15.

Roll Indicator and Horizon Bar

Roll angle is displayed by a triangular pointer that is read against a fixed roll scale. Roll attitude is shown by horizon bar rotation relative to the fixed airplane symbol. The horizon moves vertically to display pitch attitude which is read against the pitch calibration scale, using the airplane symbol center as the reference. The boxes on the horizon bar represent the airplane wingtips.

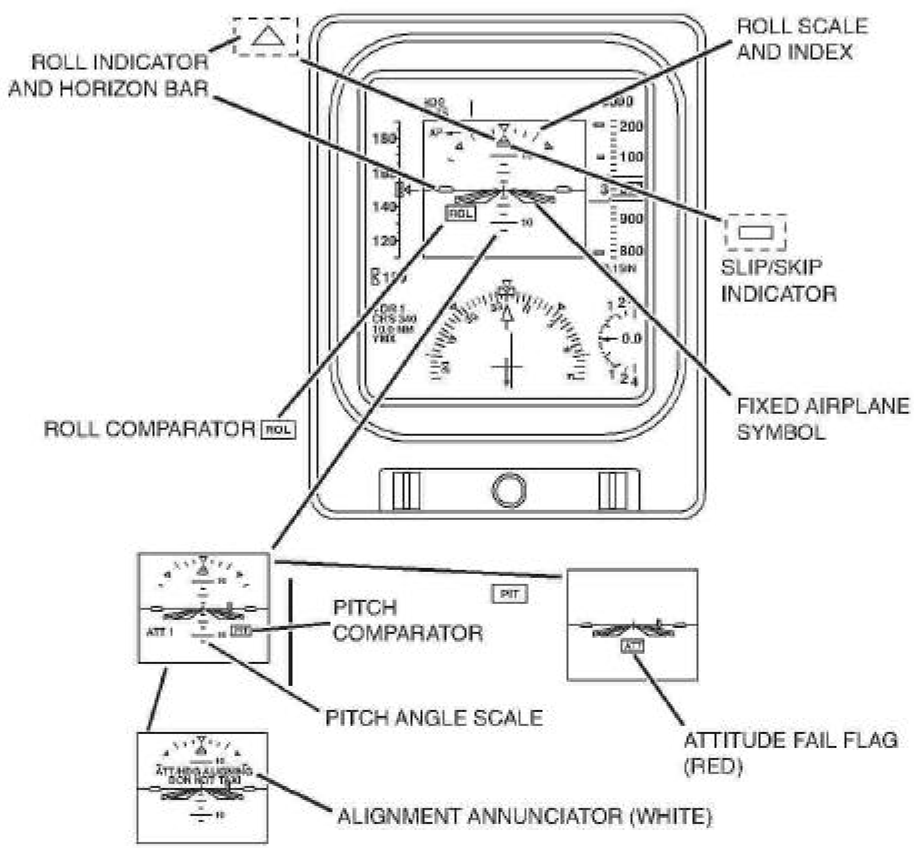


Figure 11-15 PFD Attitude Indications

Roll Comparator Flag

The yellow ROLL comparator flag is displayed when a difference of 4° (in level flight) or 3° (during approach) is detected between AHRS roll data.

Pitch Comparator Flag

The yellow PIT comparator flag is displayed when a difference of 4° (in level flight) or 3° (during approach) is detected between AHRS pitch data.

Pitch Angle Scale

Indicates pitch attitude with markings as follows:

- Small ticks at 2.5°
- Larger ticks at 5°
- Number at 10°
- Red chevrons at 30° pitch up and 20° pitch down

Attitude Fail Flag

The red ATT flag appears when attitude data fails. The PFD attitude displays loses the following pitch and roll information:

- Sky/ground image
- Pitch scale
- Roll indicator and scale
- Slip/skid indicator

Fixed Airplane Symbol

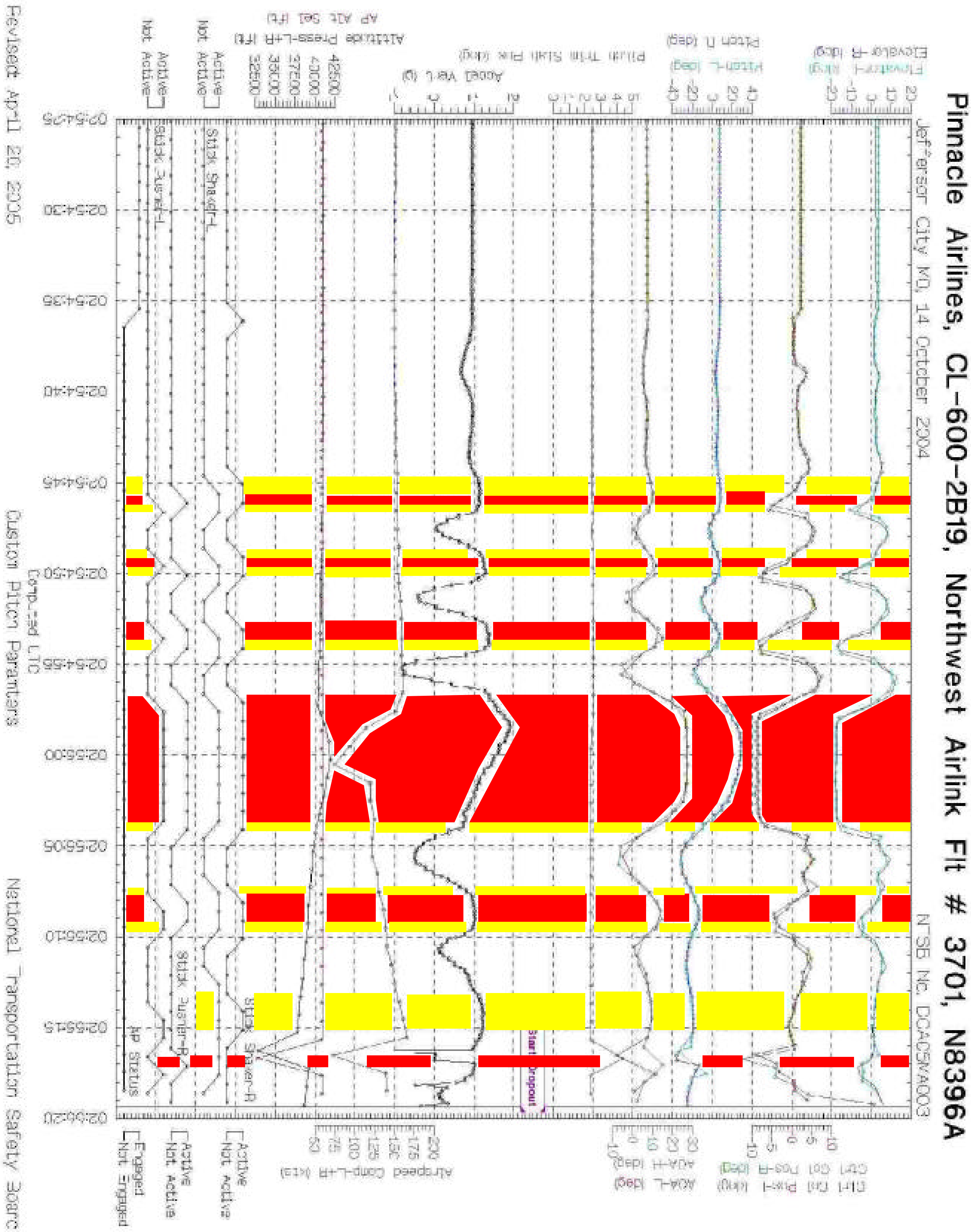
The black airplane symbol indicates the position of the airplane relative to the horizon index.

Information from the

Flight Data Recorder Group Chairman's Factual Report:

The following page contains the FDR parameters related to airspeed, attitude, and the stall protection system, with highlighting added when both stick shaker and/or pusher channels show "ENGAGE." Note that the parameters labeled AOA (Angle of attack) are recorded from the angle of attack sensors, and that input for the parameters labeled PITCH [degrees] is from the attitude and heading reference system (AHARS).

Yellow areas depict when both stick shaker channels show "ENGAGE."
Red areas depict when both stick pusher channels show "ENGAGE."



Information from Bombardier Engineering:

Bombardier Engineering provided the following data about the Basic Functionality of the CRJ-100/200 Stall Protection System (SPS).

The Stall Protection System (SPS) comprises a dual channel digital Stall Protection Computer (SPC), two AOA vanes mounted on the left and right forward fuselage sides, a shaker motor on each control column and a pusher motor connected to the right side elevator control system. There is an SPS disconnect button on each control column.

Implemented within the SPC are look-up tables, which define the AOA firing angles for the “auto-ignition”, “stick shaker” and “stick pusher”. The RJ-100/200 SPC look-up tables are functions of Mach number and flap angle. The shaker, pusher and associated aural and visual warnings are disabled with a valid weight on wheels (WOW) signal.

To reduce sensitivity to gusts and turbulence the vane AOA signals are filtered. The SPC compensates the measured AOA for the cross-flow induced effects on the windward and leeward AOA vanes in sideslip. The SPC adjusts the left and right vane AOA signals to compensate for the sideslip effects using lateral “g” from the IRU/AHRS as a programmed substitute for sideslip angle.

To protect the aircraft from inertial overshoots during accelerated stall entries at low speed the SPC incorporates an AOA phase advance function; see figure below. This function reduces the shaker and pusher AOA firing angles in proportion to the rate of increase of AOA, up to a pre-set maximum. The CRJ-100/200 phase advance on the shaker is not enabled until three seconds after weight-off-wheels during take-off, and is then phased in progressively over one second. The pusher retains its phase advance throughout the take-off. The phase advance for shaker and pusher is disabled above a pre-set Mach number (M>0.52).

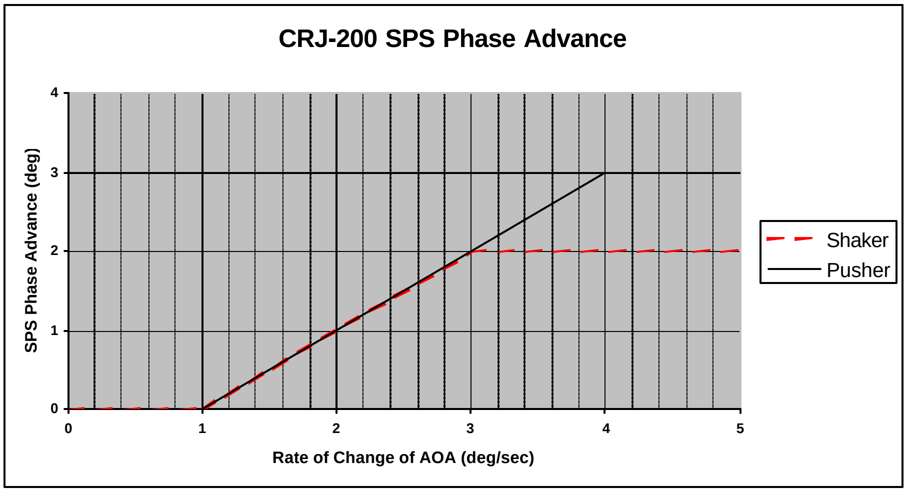
Cancellation of the stick pusher occurs at a lower AOA than the tabulated stick pusher firing angle (hysterisis) to ensure that the push is of sufficient duration. However, to minimize negative “g”, in for example recovery from high speed or high altitude pusher stalls, there is a phase advance term applied to the basic stick pusher cancellation hysterisis term. The phase advance reduces the basic cancellation hysterisis term as a function of the AOA rate on recovery; see equation below.

If the signal from one of the AOA vanes exceeds the programmed “auto-ignition” firing angle, it will cause the activation of both engine auto-ignition systems. At a higher AOA, and if the signal from one of the AOA vanes exceeds the programmed “shaker” firing angle, it will cause the activation of the stick shaker motor on that side, and if the autopilot is selected it will be automatically dis-engaged at this time. Both the pilot and co-pilot’s sticks will shake because they are mechanically connected. If both AOA vanes exceed the “shaker” firing angle, both stick shaker motors will be activated. At even higher AOA, and if the signal from one of the AOA vanes exceeds the programmed “pusher” firing angle, it will trigger the “stall” aural warning and the onside flashing red “STALL PUSH” warning light. If both vane AOA’s exceed the “pusher” firing angle the stick pusher motor will be activated. The stick pusher motor will apply an approximately 80 lbs forward force to the control columns. The motor will cease to be active, and the 80 lbs push force removed, once the AOA of the aircraft reduces below a preset value below the pusher threshold.

The SPC also provides normalized AOA data for other aircraft systems e.g. the “green line” (FAA aircraft only), the barber pole low speed cue, and the Windshear detection and guidance systems.

The SPC converts the “filtered” stall vane AOA into body AOA for output to the DFDR; see equation below. The AOA recorded on the DFDR is not compensated for sideslip.

Figures showing the firing angles and sideslip compensation are provided below:



		CRJ-200
Phase Advance "cap"	**Shaker**	**2**
	Pusher	**3**
Phase Advance Time Delay After WoffW	**Shaker**	**3+fade in**
	Pusher	**0**

Equation for conversion from AOAVane to AOABody(Fuselage) – valid for all flap angles, Ref. FSW/91/601R/073/VT**;**

$a_{\text{FUSELAGE}} = 0.845 + 0.602 * a_{\text{STALL VANE}}$

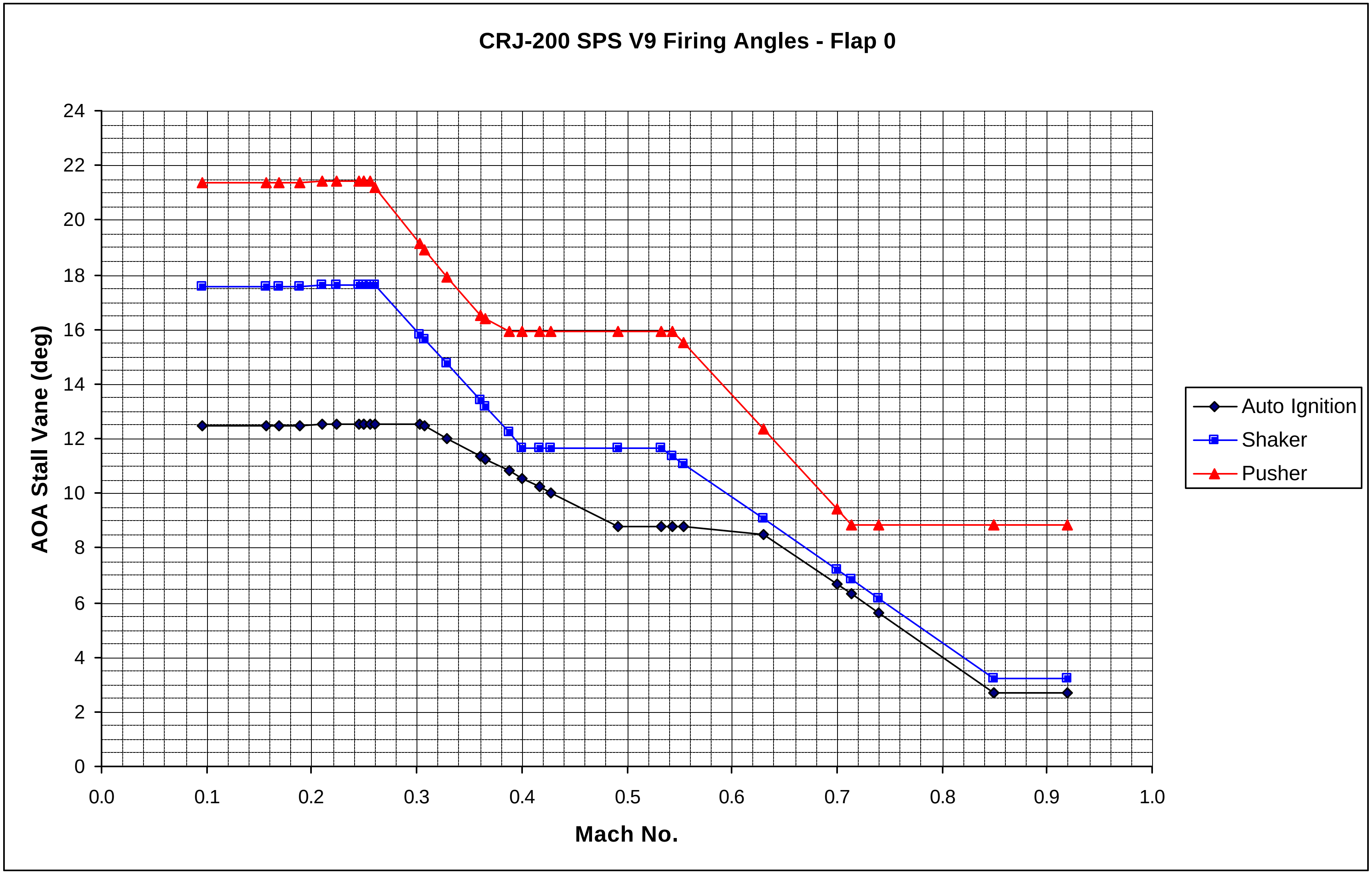
Pusher Cancellation Term, Ref. MAA-601R-325:

$a_{\text{CANCEL}} = a_{\text{F PUSH}} - \text{hysterisis}$

Where:

$\text{hysterisis} = 5.5° + 0.75 * da/dt$

da/d**t is the rate of change of angle of attack.**


CRJ-200 SPS V9 Firing Angles - Flap 0
AOA Stall Vane (deg)
Mach No.
Auto Ignition
Shaker
Pusher
0
2
4
6
8
10
12
14
16
18
20
22
24
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

PREPARED S. N. Nasry
CHECKED H. Sadek
APPROVED C. E. Tanner

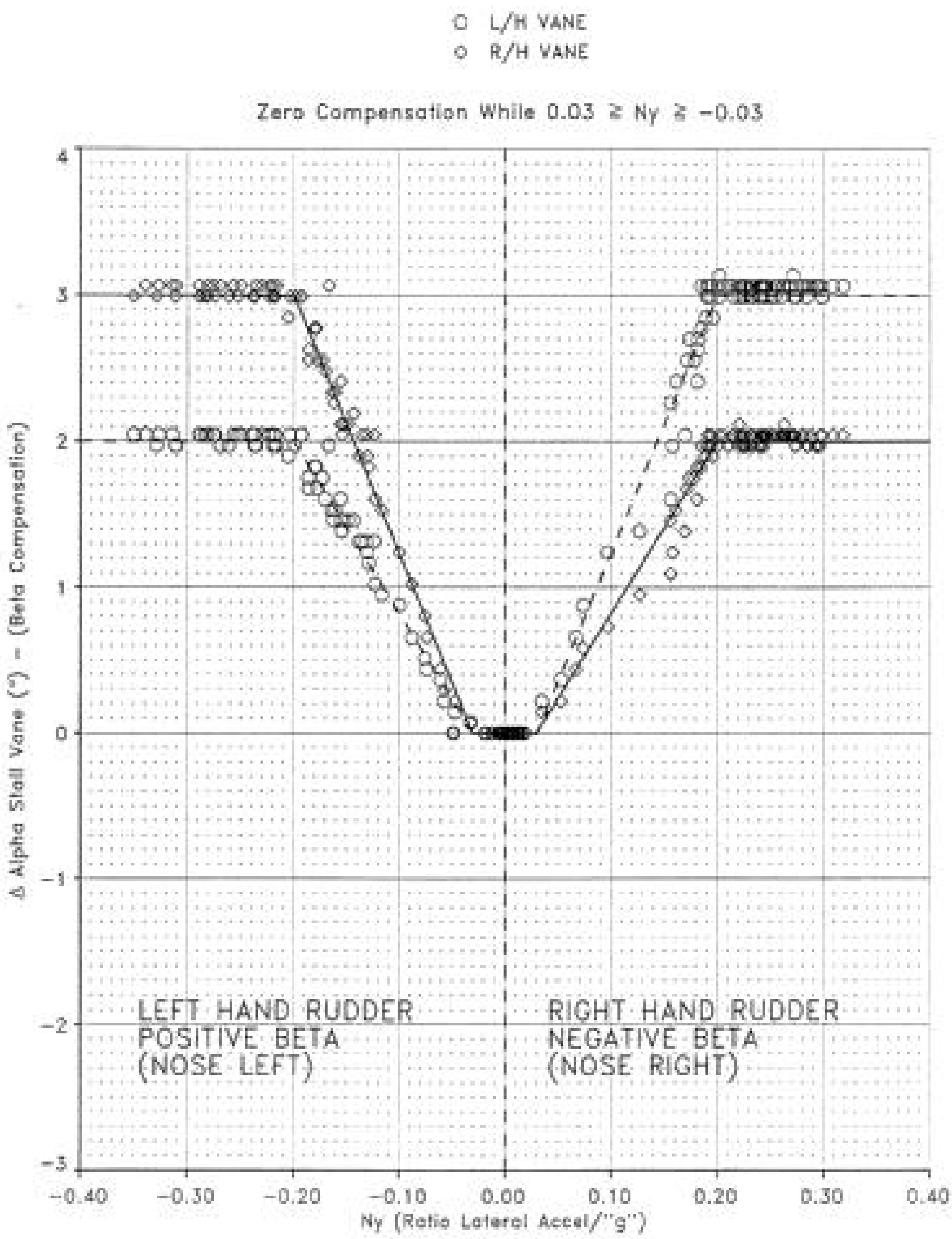
BOMBARDIER canadair

MODEL CL-601R (RJ)

PAGE 8
REPORT MAA-601R-325E
DATE Dec 12 1996

SUBJECT:

Fig. 3 Static Lateral and Directional Stability
A/C 7002, Flight 779, Flap 0°
STALL VANE SIDESLIP COMPENSATION



11:33:56 to 11:34:40 & 11:43:30 to 11:45:50