GARMIN 1000NXI SUPPLEMENTAL MATERIAL

The airplane was equipped with a Garmin G1000NXi and a Garmin GFC700 autopilot. The flight was being recorded to establish base line performance information after adding an Aircraft Payload Extender III (APE III) modification but before adding modification for an aerodynamic drag reduction system (DRS) on the Cessna 208B EX model. The software loaded was version 2499.10, which could be seen in a video recording at the beginning of the flight.

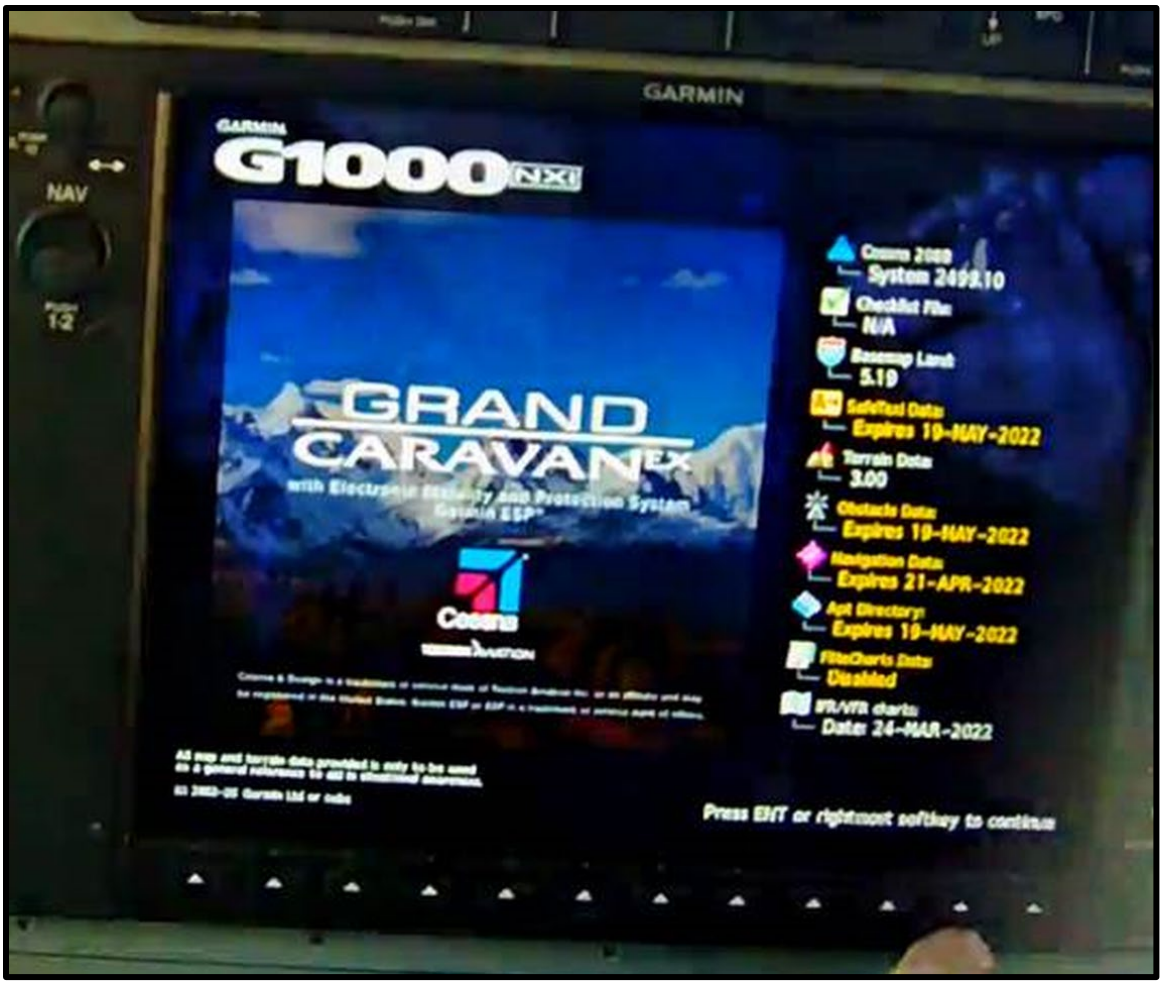

Figure 1: Accident Unit

The Garmin G1000NXi is an integrated glass cockpit. Included is an electronic flight instrument system (EFIS) composed of 2 primary flight displays (PFD's) and a multi-function display (MFD). Incorporated is the GFC 700 Automatic Flight Control System (AFCS), a fully digital, three-axis, dual channel, fail passive autopilot. This airplane was also equipped with an Electronic Stability and Protection (ESP) system.

FLIGHT 07

Flight 7 was the last flight recorded the day before the accident flight. The purpose of the flight was to evaluate the airplane's aft center of gravity (CG) stall characteristics. The flight departed Renton City Municipal Airport (RNT) on northbound heading to an uncongested area in Snohomish County to complete the planned series of stalls (See Figure 2). During the flight, 10 of 12 stalls were performed on the flight test card (See Figure 3). The maneuvers were to be performed between 8,000 and 10,000 ft mean sea level (MSL). All 10 maneuvers were executed with the yaw damper (Y/D) and autopilot (AP) off. The first 4 stalls were straight ahead and the remaining 6 stalls were in a 30° banked turn to either the left and right, with the flaps in the UP and Landing positions.

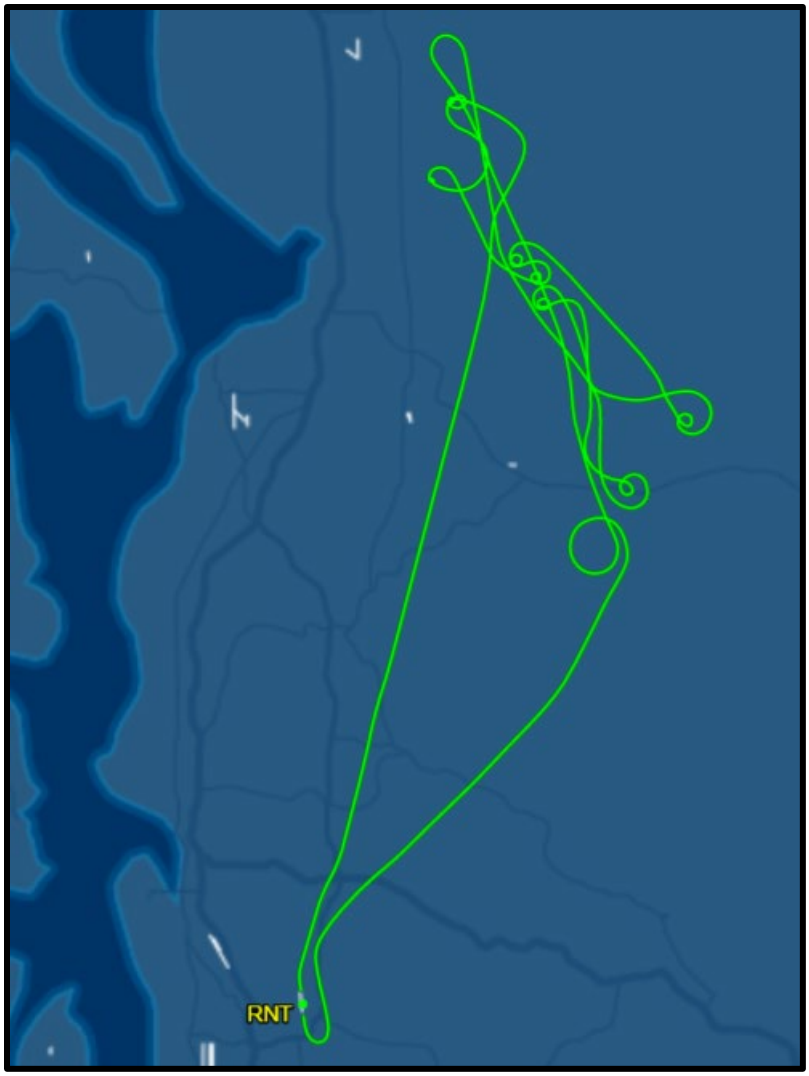

Figure 2: Flight Track

	COND	Altitude	Target Speed KIAS	FLAP	Torque Ft-Lb	Propeller RPM	APPROX WEIGHT	FUEL REMAINING	REMARKS
	Takeoff	Airport	(83/104)	Up	2397	1900	9,046	2,246	Normal takeoff. Make note of handling characteristics
1	5.1	8,000-10,000	1.5 Vs (117)	Up	Idle	Full Fwd	8,933	2,133	Straight Stalls. Y/D Off. Use elev to decel approx -1.0 kt/sec.
3	5.2	8,000-10,000	1.5 Vs (90)	Land	Idle	Full Fwd	8,917	2,117	Straight Stalls. Y/D Off. Use elev to decel approx -1.0 kt/sec.
2	5.3	8,000-10,000	1.5 Vs (117)	Up	930	Full Fwd	8,900	2,100	Straight Stalls. Y/D Off. Use elev to decel approx -1.0 kt/sec.
4	5.4	8,000-10,000	1.5 Vs (90)	Land	930	Full Fwd	8,884	2,084	Straight Stalls. Y/D Off. Use elev to decel approx -1.0 kt/sec.
1	5.5L	8,000-10,000	1.5 Vs (126)	Up	Idle	Full Fwd	8,868	2,068	Turning 30° Bank Left. Target -1.0 kt/sec
2	5.5R	8,000-10,000	1.5 Vs (126)	Up	Idle	Full Fwd	8,852	2,052	Turning 30° Bank Right. Target -1.0 kt/sec
5	5.6L	8,000-10,000	1.5 Vs (96)	Land	Idle	Full Fwd	8,835	2,035	Turning 30° Bank Left. Target -1.0 kt/sec
6	5.6R	8,000-10,000	1.5 Vs (96)	Land	Idle	Full Fwd	8,819	2,019	Turning 30° Bank Right. Target -1.0 kt/sec
3	5.7L	8,000-10,000	1.5 Vs (126)	Up	930	Full Fwd	8,803	2,003	Turning 30° Bank Left. Target -1.0 kt/sec
4	5.7R	8,000-10,000	1.5 Vs (126)	Up	930	Full Fwd	8,787	1,987	Turning 30° Bank Right. Target -1.0 kt/sec
7	5.8L	8,000-10,000	1.5 Vs (96)	Land	930	Full Fwd	8,770	1,970	Turning 30° Bank Left. Target -1.0 kt/sec
8	5.8R	8,000-10,000	1.5 Vs (96)	Land	930	Full Fwd	8,754	1,954	Turning 30° Bank Right. Target -1.0 kt/sec

Figure 3: Excerpt of Test Card

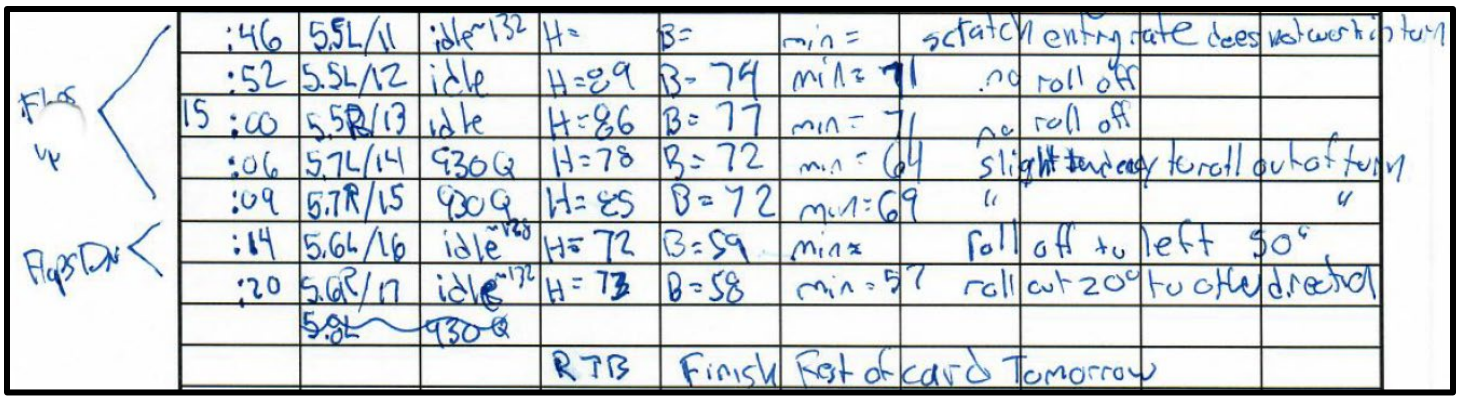

Figure 4: Test Director Notes

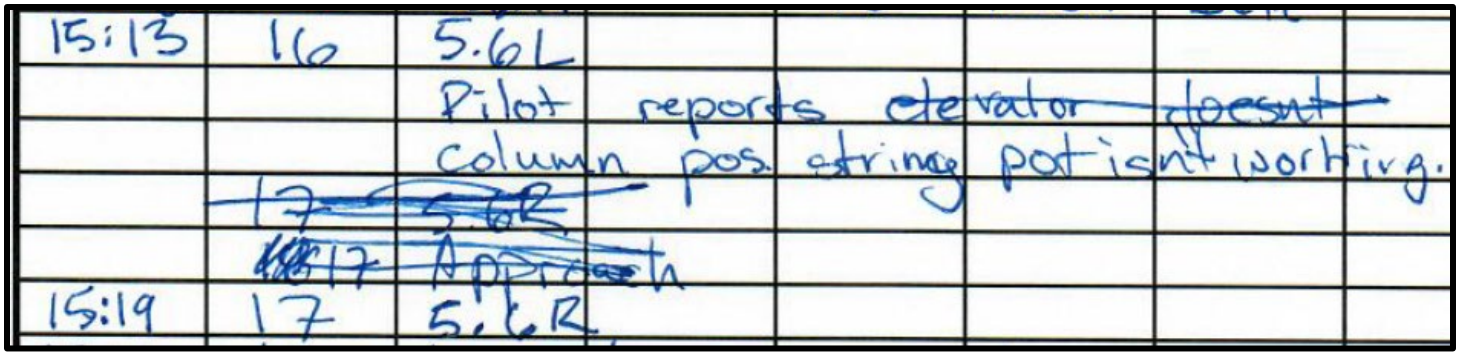

Figure 5: Instrument Lead Notes

Flight 07 was recorded with audio and video. A camera was placed over the left-seat pilot's right-shoulder. This was to aid the flight test engineers in gathering data and was utilized in post flight data review. For the 5.7L and 5.7R tests, the maneuver was to begin at 96 knots indicated airspeed (KIAS) in a 30° bank, power at 930 foot-pounds (ft-lbs) of torque, and flaps in the up position. For the 5.6L and 5.6R tests, the maneuver was to begin at 96 KIAS in a 30-degree bank, power at idle, and flaps in the landing position. The target parameter for both exercises was to slow 1 kt per second until reaching a stall and recover. The pilots and engineers would note the airspeed at the stall warning horn, low-speed stall buffet, and the minimum airspeed where the stall occurred. The maximum bank angle was noted during the stall recovery. The maneuver was considered passing if the bank angle did not exceed 60° (as per FAR Par 23.203(a)(4)) and rejected if bank angle went beyond. The elevator was held at the aft stop (full back pressure on the control column) for two seconds before the pilot-initiated recovery if the stall did not break at the minimum airspeed

The left turning stall designated as 5.7L started at 96 KIAS. The pilot stated "Stall warning at 78, buffet at 72... pitching out at 64… slight tendency to want to roll out of turn." No minimum speed was verbalized. The pilot then began the right turning stall designated as 5.7R at 130 KIAS. The pilot stated "Warning 85, buffet at 72…full stop, 1 potato 2 potato… slight tendency to want to roll out of turn." The video showed during the turning stall to the right the airplane rolled back to the left and the minimum speed was recorded at 69 KIAS.

Maneuver 5.6L began at 96 KIAS and 30° bank to the left. The pilot stated "Stall warning at 72… buffet at 59…" and then presumably following the stall he added "just out of curiosity, this column position, what is it telling me?" There was confusion between the pilot and engineer about elevator column input and elevator position. The pilot was told full elevator travel would be 100% at full stop. The pilot says he is only seeing 13-14% at aft stop. The pilot was asked if during the stall if the bank angle exceeded 60 degrees, and then stated "No, we were only about 50… so technically I guess that's good… it's a pass, " and "Glad you mentioned it because I was going to reject it… it rolled and I couldn't stop it, but I pushed out and it was still within." The pilot was queried if the elevator was at the aft stop, and he said he believed it was because he was pulling and didn't see any more movement. The video shows the maximum roll was 83 degrees. The airspeed indicator began flashing an amber caution advisory at 140 KIAS and continued to 153 KIAS before the downward pitch was corrected.

Maneuver 5.6R began at 96 KIAS, and a 30° bank turn to the right. The pilot stated "Stall warning at 73… buffet at 58… push out 20° other direction… it was on its own". Minimum speed was recorded at 57 KIAS. After the maneuver was complete there was discussion about completing the last 2 stalls on the card. The instrument lead was airsick, and the pilot expressed he was also about ready to be done. They debated if they should end the flight testing and finish the remainder of the test card the next day. The video shows during the conversation the pitch attitude rose 15° nose up airspeed at 66 KIAS then nose down to 25° with a peak rate of decent momentarily at 7,200 fpm. Airspeed increased and a caution advisory flashed amber at 140 KIAS. The airspeed continued increasing as a warning advisory alerted the pilot of never exceed speed (Vmo) at 175 KIAS. The airspeed increased to 183 KIAS before the overspeed condition was corrected.

ELECTRONIC STABILITY PROTECTION (ESP)

The ESP is an optional software upgrade on the Garmin G1000 NXi flight deck. It operates through the air data computers, the attitude and heading reference system (AHRS) and autopilot servos in the integrated avionic systems independently of the autopilot. This feature intends to deter attitude and airspeed exceedances while the pilot is hand-flying and assist in maintaining the airplane in a stable flight condition. ESP will only function when the aircraft is above 200 ft above ground level (AGL) and the autopilot is not engaged.

The airplane manufacturer determines the parameters when the ESP activates. When the pilot exceeds the pitch, roll or airspeed limitations it corrects on the flight controls to lessen the airplane's pitch, attitude, or bank angle. The correcting force becomes stronger if the exceedance grows further away from the preset limits. A maximum engagement limit is applied to all conditions except high airspeed. Above the maximum engagement limit, control correcting forces are no longer applied.

The ESP can be enabled or disabled in a System Setup page within the multi-function display (MFD). It can also be interrupted by the pilot by pushing and holding either Control Wheel Steering (CWS) or Autopilot Disconnect (AP DISC) switch on the control yoke. Upon releasing either switch, ESP will again apply control force, provided aircraft attitude and/or airspeed are within engagement limits.

In the G1000/G1000 NXi to disengage the autopilot requires:
Use the FMS knob to select the Aux-System Setup Page.
If necessary, press the Setup 2 Softkey to display the "Aux- System Setup 2" Page.
Push the FMS Knob to place the cursor in the "Stability & Protection" Field.
Turn the small FMS Knob to select "Enabled" or "Disabled."
Push the FMS Knob to deactivate the cursor.

ROLL ENGAGEMENT

Roll Limit Indicators bars are displayed on the attitude indicator where the 45° left and right bank hash marks are located. This indicates that the ESP will engage as the roll exceeds 45° and the Roll Limit Indicator bars will move to the 30° and 75° degree positions, which shows where ESP will disengage as roll attitude increases/decreases (i.e., ESP will disengage once roll is returned to 30° or beyond 75°). Once engaged, ESP force varies up to a maximum force of 7.5 lbs. The force increases as bank angle increases with maximum servo torque attained at 60°.

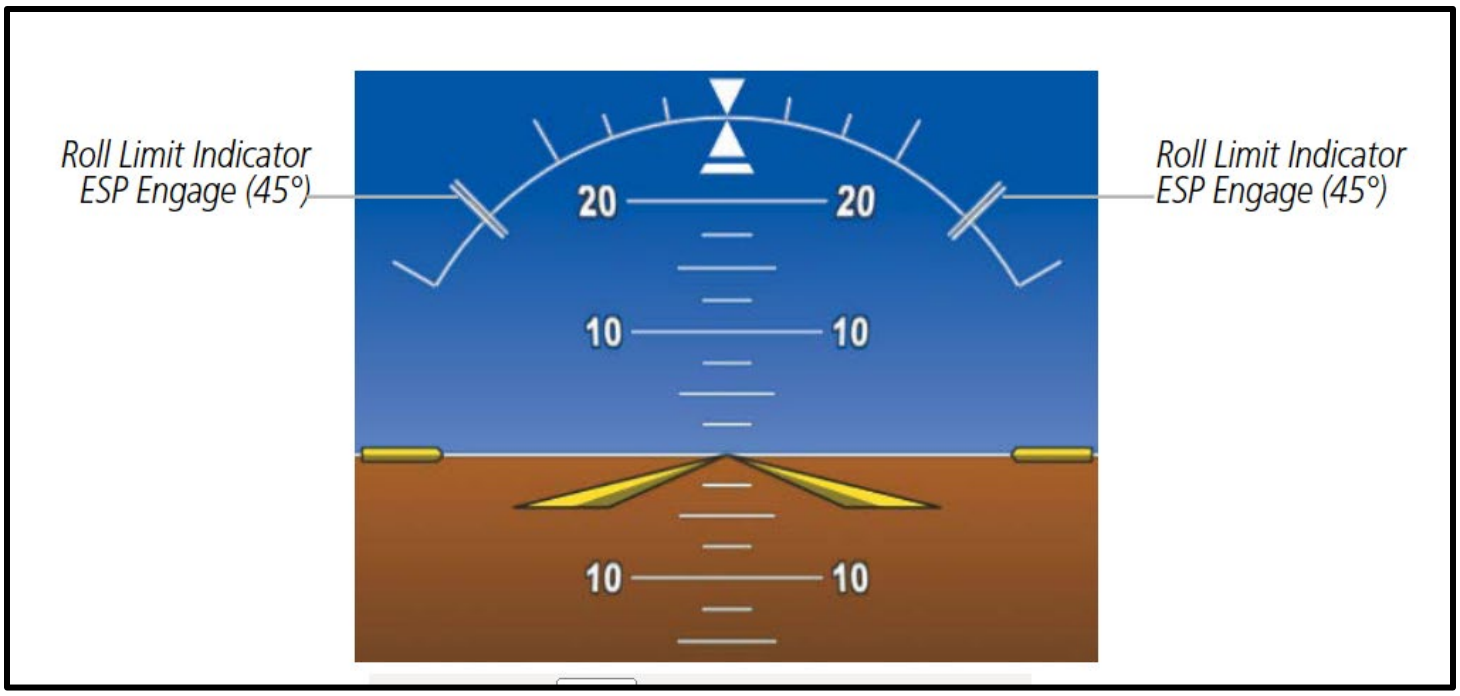

Figure 6: ESP roll engagement indication (ESP not engaged)

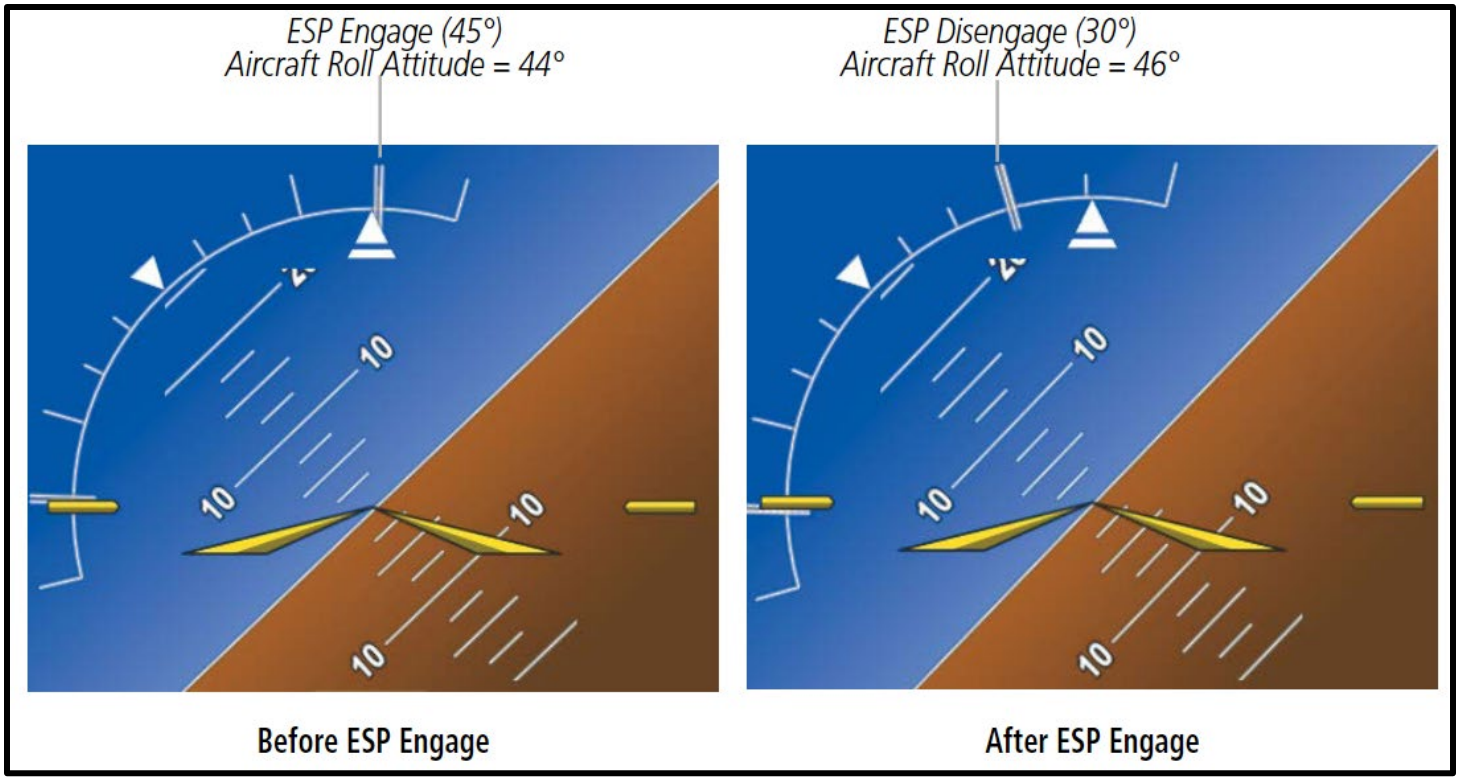

Figure 7:Roll increasing to ESP engagement

PITCH ENGAGEMENT

According to the Garmin G1000 NXi Pilot's Guide of the Cessna Caravan:

> The ESP system engages at 19° nose-up and 20° nose-down. Once engaged, it applies opposing force between 17° and 50° nose-up and between 18° and 50° nose-down. Maximum opposing force is applied between 24° and 50° nose-up and between 25° and 50° nose-down. The opposing force increases or decreases depending on the pitch angle and the direction of pitch travel.

There are no indications marking the pitch ESP engage and disengage limits in these nose-up/nose-down conditions, nor is there an indication when it is activated.

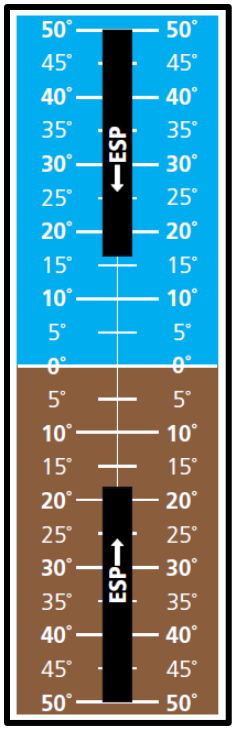

Figure 8: ESP Pitch operating range when engaged

AIRSPEED PROTECTION

If Vmo is exceeded (175 kts) the ESP activates and applies force to raise the nose of the aircraft until the overspeed condition is resolved.
There is no minimum airspeed protection.

ESP AUTOPILOT ENGAGEMENT

When ESP has been engaged for more than 10 seconds cumulative, not necessarily consecutive seconds, of a 20 second interval, the autopilot is automatically engaged with the flight director in Level Mode, bringing the aircraft into level flight. An aural "Engaging Autopilot" alert is played, and the flight director mode annunciation will indicate LVL for vertical and lateral modes.

For disengagement, the Garmin manual states:

> When the autopilot is engaged, a small amount of pressure or force on the pitch controls can cause the autopilot's automatic trim to run to an out-of-trim condition. Therefore, any application of pressure or force on the controls should be avoided when the autopilot is engaged. Overpowering the autopilot during flight will cause the autopilot's automatic trim to run, resulting in an out-of-trim condition or causing the trim to hit the stop if the action is prolonged. Unanticipated control forces are required after the autopilot is disengaged.

PRIOR FLIGHT

A review of the cockpit video from Flight 07, revealed that the pilot activated the autopilot and yaw damper on several occasions. At a recorded time of 1514:51, when the pilot was performing the stall for the test point 5.6L, the airplane rolled left and passed the 45° threshold which was seen to activate the ESP (the Roll Limit Indicator Bars moving). The airplane continued to roll past 75° and reached a maximum roll of about 83°, before returning to level.

Figure 9: Airplane PFD showing past 75°

At 1521:44 as the pilot was leveling off and having recovered from a stall, the pilot had the airplane pitching in a nose-low attitude in excess of 30°. The attitude indicator displayed red chevrons pointing up indicating an unusual attitude. The magenta airspeed trend vector line predicted Vmo within 6 seconds and the actual airspeed readout turned yellow.

Figure 10: Airplane's PFD displaying red chevrons and the amber airspeed

At 1521:45 the autopilot turned on into LVL mode indicating that the airplane was below the nose-down attitude of 20° for more than 10 seconds. There is a beeping in the cockpit and the MAXSPD amber warning illuminated as the speed increased to 183kts. The autopilot disconnected at 1521:53, presumably by the pilot disengaging it on the control yoke. Thereafter, the Instrument Lead became airsick and they decided to return back to base.

Figure 11: Autopilot activating from ESP engagement

According to a Garmin representative, the pilot would only be aware that the ESP is activated by additional control force of if the roll bar indicators go beyond the 30° of roll. He stated that the operation of ESP is akin to a flight instructor gently nudging the flight controls towards a normal flight condition. Since there is a display indication and a tactile flight control indication, any additional indication (e.g., aural) was thought to be distracting.

The maximum force applied by the ESP is selected by the airplane manufacturer (the certifier),but he stated it is typically 15 pounds or less at the cockpit control. It is not intended as a stick pusher or a Fly-By-Wire system that takes away control from the pilot but is an additional indication that the airplane is straying outside what the manufacturer has determined to be the normal operational envelope of the airplane. The force varies from 0 lbs at 30 degrees of bank to maximum at 60 degrees of bank. When the angle of bank exceeds 45 degrees, ESP engages at 50% of the maximum force, i.e., typically 7.5 lbs, and then varies linearly between 30 degrees and 60 degrees angle of bank. It engages at 45 degrees because Garmin wanted to ensure the pilot noticed that ESP had activated, and gradually starting at 30 degrees bank did not provide that notice.

The system will not disconnect due to the pilot applying countering force. It is designed such that the pilot can accurately control the airplane in the ESP range even with the maximum ESP force, and this is demonstrated during certification.

The ESP system disengages at 75 degrees angle of bank because that is the maximum engageable limit of the autopilot. When the angle of bank exceeds 75 degrees or is less than 30 degrees, ESP force stops instantaneously. It will immediately re-engage when the engagement parameters are met (returning to less than 75 degrees or increasing to more than 45 degrees angle of bank).

The pitch control force is also selectable by the certifier and is also typically 15 pounds maximum. The autopilot system is limited by Gs, typically 1.3G, with some manufacturers allowing as much as 1.5G. The ESP system is similarly limited. It merely inputs its force as a function of pitch attitude or airspeed (and in some installations, AOA) and is clipped (i.e., no force commanded) if the G limit is exceeded. The ESP will not disengage at a specific pitch force. It will disengage when the ESP engagement parameters are no longer met. (aircraft speed or pitch attitude). However, the automatic pitch trim is disabled when ESP is active, so when the ESP system disconnects, the trim is in exactly the same position it was when ESP went active. Also keep in mind that, as the airplane accelerates or decelerates, the natural static longitudinal stability of the airplane is the predominant pitch force, not ESP.

As long as the angle of bank is not within +/- 75 degrees, neither the autopilot or ESP will operate.

The autopilot system as a whole, and including ESP, has no knowledge about what is being done with the rudder. For an airplane with a yaw damper – like the C208 with G1000 NXi – the yaw damper will activate to null any yaw, but the roll channel does not modify its behavior based on any yaw damper input. The roll channel seeks only to satisfy whatever the lateral command selected by the pilot is, whether that is roll attitude, heading, course, etc.

According to Textron Aviation, there are three main types of ESP for the 208B: pitch, roll, and high speed. For each of these, the starting torque is 0 in-lbs and the maximum torque is 43.2 in-lbs. There are curves that define the strength of the force based on how the aircraft is maneuvering.
The following example was provided with no numerical values included.

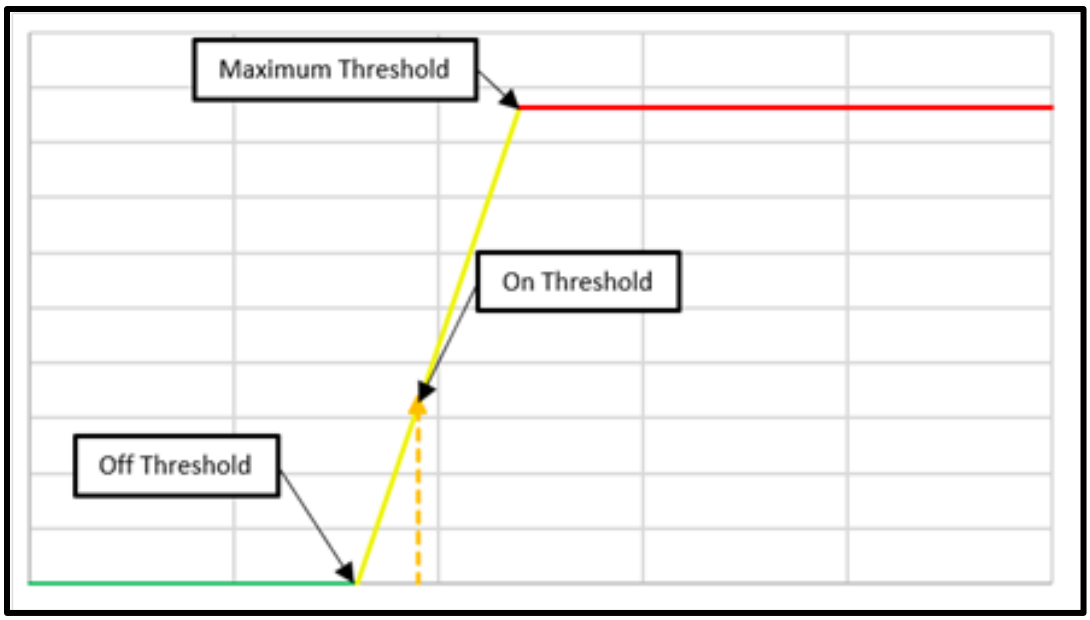

Figure 12: Textron provided graph of force from ESP