AIRBUS FlyByWire – How it really works

Comparison between APOLLO's and Phoenix PSS Airbus FlyByWire implementation for FS2002

The FlyByWire control implemented on Airbus aircraft series A320, A330 and A340 differs in many ways from conventional aircraft control such as that found on Boeing B737, B747 and even on the latest B777. None of the aircraft that come with Microsoft Flightsimulator are protected against Controlled Flight into Terrain (**CFIT**) or have a modern Flight Envelope Protection, as implemented on the latest Airbus aircraft.

This is implemented for the very first time by an add-on product for Microsoft Flightsimulator, the new „FlyByWire Airbus" simulation title by APOLLO Software Publishing Ltd..

In conventional aircraft, the movement of the yoke is transformed into a linear, direct proportional deflection of the rudders and control surfaces. This is irrespective of whether the input is then transmitted via electric cables and subsequently enhanced by additional hydraulic systems. The maximum movement of the yoke will result in the maximum deflection of the control surfaces, and accordingly, they will revert back to neutral position if the yoke is moved back into the center position.

This is very different from the way it is implemented by the advanced FlyByWire mechanism of the modern Airbus aircraft: By applying a command using the airbus sidestick the pilot does not command a deflection of the control surfaces but instead he 'demands' a change in the flight path trajectory. Based on this input the Airbus control computers then calculate and execute the deflection of the control surfaces required to achieve the 'demanded' change in flight path.

Conversely with no input on the sidestick, i.e. leaving the sidestick in the neutral position, instructs the Airbus control computer that no change of the current flight path is required. While this may sound trivial, it still has important consequences, because this applies also during speed or configuration changes, i.e. during speed in- or decrease or during ex- and retraction of flaps or gear. All such activities would change lift, drag and speed and as a result would cause a conventional aircraft to begin a climb or descent. To avoid such changes in flight path and airspeed, the pilot would have to counteract by re-trimming the aircraft and adjusting power setting accordingly.

The control computers of the Airbus compensate for all such changes and applies control surface deflections and power settings automatically, relieving the pilot from these routine housekeeping tasks.

Contrary to statements found frequently in other articles, this is not just automatic trimming but automatic adjustments of the control surfaces and power setting to maintain the requested flight path. Sure, the Airbus is also equipped with automatic trim but it would react far too slow to compensate for such configuration changes or those caused by turbulence. The automatic trim in an Airbus is continuously re-adjusted automatically within 30 seconds to keep the control surfaces centered, in order to have maximum travel available both directions for sudden maneuver changes.

In conventional aircraft if the pilot wants to change the heading, he would bank the aircraft by moving the yoke left or right. The airplane will then start to bank according to aileron/rudder setting and fly a curve. The following will happen: due to increased bank angle lift will be reduced and the plane begins to sink. If the pilot pushed the yoke then back to neutral, the plane will not maintain the current bank angle but due to its self-stability will eventually turn back into a level position. In order to maintain a constant „turn rate" the pilot of a conventional aircraft will have to continuously make rudder and elevator adjustments or re-trim the airplane during the turn.

In the FlyByWire equipped Airbus however, the pilot commands a bank rate simply by shifting the sidestick left or right, for example he may command an angular speed of 3 degrees/sec along the longitudinal axis of the plane. The control computer then calculates and activates the control surfaces and adjusts the power setting required to achieve the constant bank rate while increasing the bank angle. Once the Airbus has reached the desired bank angle (30 degrees for example) the pilot simply releases the sidestick. The sidestick returns back to neutral which tells the control computer: „no further changes requested, now you computer please maintain the current attitude of the airplane“. The current attitude of the airplane in this case would be kept at 30 degrees of bank angle, while maintaining a constant altitude. The Airbus will continue to fly perfect circles, maintaining the current bank angle and automatically adjusting any loss in lift by increasing the pitch angle with no further input required by the pilot. Just before the desired heading has been reached the pilot would push the stick into the opposite direction, thus commanding a bank rate about the longitudinal axis of the airplane until the plane flies straight and level again. Now the pilot releases the sidestick again.

The maximum possible bank rate around the longitudinal axis is 15 degrees per second, which is similar to „jet fighter aircraft“ performance. In real life, Airbus pilots avoid such sudden maneuvers to maintain passenger comfort.

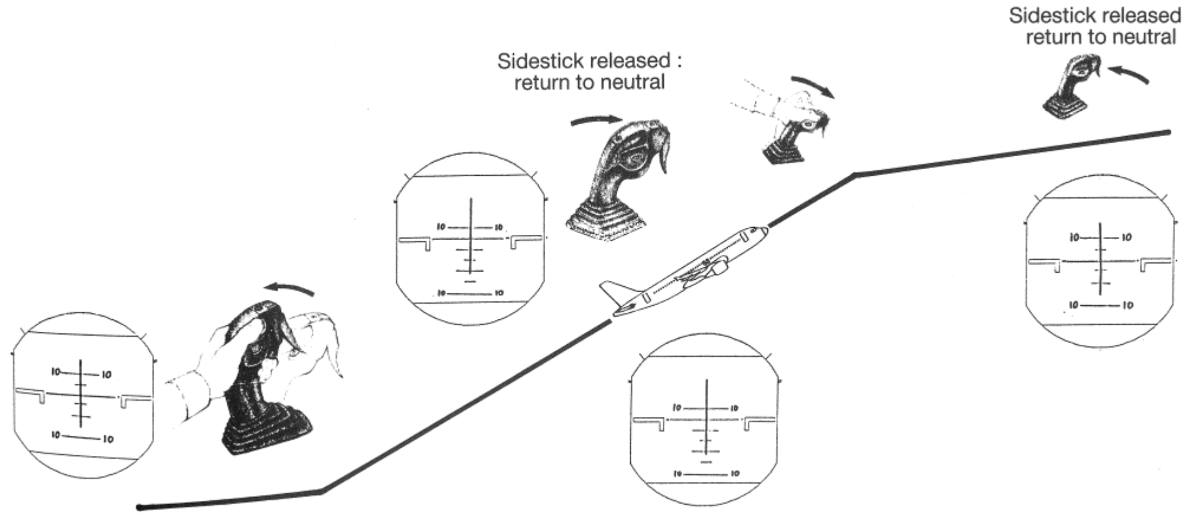
But the Airbus can do even more: if the bank angle has increased to more than 33 degrees and you put the sidestick back into neutral position, the aircraft will automatically turn back and maintain a fixed bank angle of 33 degrees until the pilot commands another attitude. The maximum bank angle is limited to 67 degrees, pushing the sidestick still further will still keep the bank angle fixed at 67 degrees.

To change altitude in a conventional aircraft, you either push or pull on the yoke to change the position of the elevator, which in turn results in a specific pitch angle. In order to avoid having to keep pulling or pushing the yoke over an extended period of time until the new altitude has been reached, the airplane can be trimmed which allows the yoke to be moved back in a neutral position. After the new altitude has been reached, the airplane needs to be re-trimmed again. While pulling back on the yoke during steep climbs, it is essential to not apply too much, otherwise the angle of attack increases to a point where the wings no longer produce sufficient lift and the aircraft can not be controlled due to lack of laminar airflow around the wings. Subsequent a deadly stall can occur.

In the FlyByWire Airbus, by pulling or pushing the sidestick the pilot commands a change of the acceleration: under constant trajectory conditions a g-force of 1 g is applied to the aircraft, pilots and passengers, as on the ground. By pulling on the stick the pilot commands an increase in g-force acceleration for example by 0.2 g from 1 g to 1.2 g. This increase of the g-force acceleration is achieved by rotating around the lateral axis of the aircraft, which will lift the nose of the airplane. The centrifugal force (resulting from the vertical circular segment the plane is following) of this rotation is added to the normal g-force, for a total of 1.2 g's.

Likewise, by pushing the sidestick forward the pilot commands a reduction of the g-force by 0.2 g to 0.8 g. The airplane reduces the g-force by rotation around the lateral axis and lowers its nose (the center of rotation of the vertical circular segment the plane is following is below the aircraft, therefore the centrifugal force subtracts from the g-force). This change in g-force is directly proportional to the sidestick deflection.

To initiate a climb, the airbus pilot pulls the stick, thereby commanding an effective g-force of for example 1.3 g. The airplane will rotate around the lateral axis while constantly increasing the pitch angle and the vertical direction the airplane is moving in, until the sidestick is put back into the neutral position. Neutral stick position tells the control computer to maintain the current flight path vector. Along this vector the standard g-force of 1 g is applied The control computer adjusts power and control surfaces as needed to maintain this attitude. Changes in speed or configuration (flaps, gear etc.) will have no affect on the flight path vector, as depicted in more detail in the following diagram:

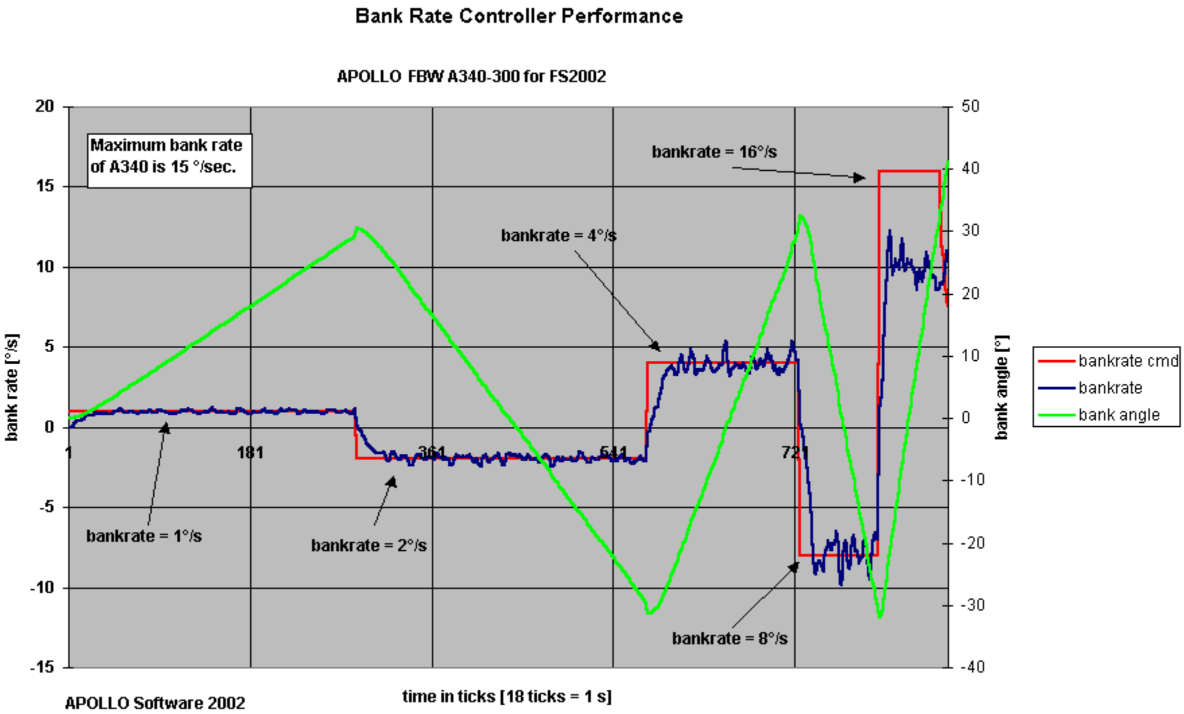


Sidestick released :
return to neutral
Sidestick released :
return to neutral

Flight Envelope Protection.

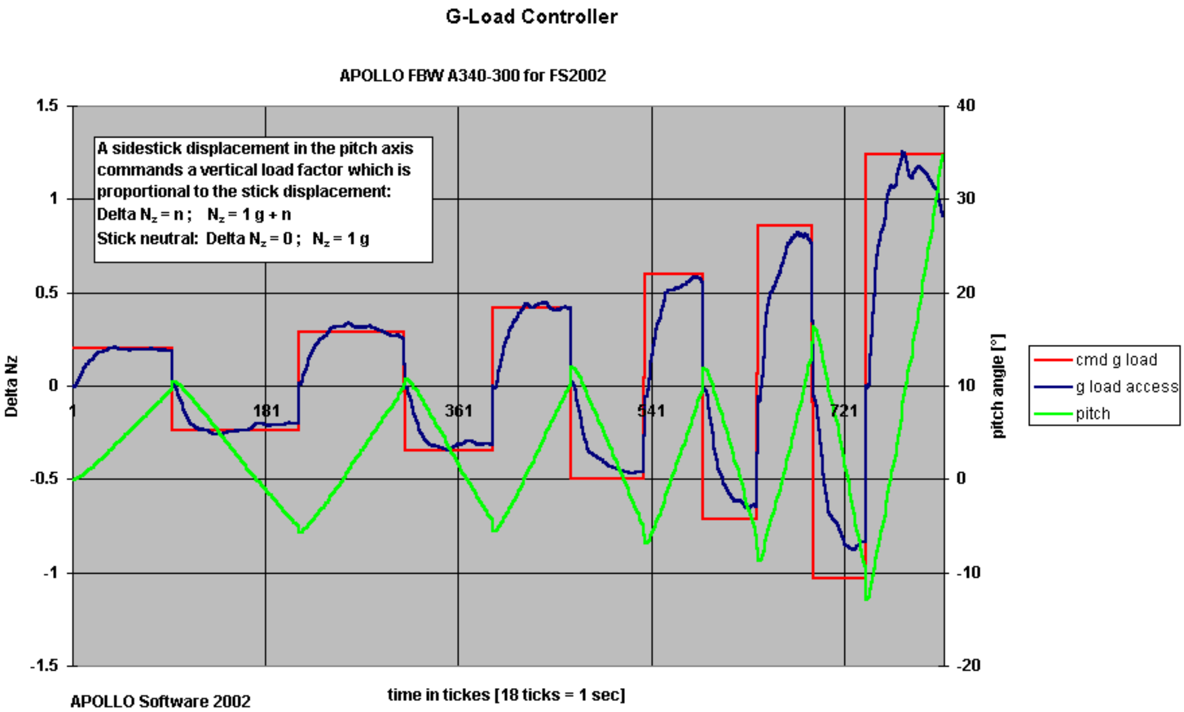
The maximum g-force acceleration (load) is limited to – 1.0 g and + 2.5 g, depending on the specific flight phase. Pitch angle is limited to a range of + 30 (25) and –15 degrees.

The bank rate controller adjusts movement along the longitudinal axis, the g-load controller is responsible for the lateral axis. For the characteristics of these two controllers, as implemented by APOLLO's FlyByWire software for Microsoft Flightsimulator 2002, refer to the following diagram:



In the diagram above, the pilot sidestick input is depicted in red, showing 5 different values of bank rate commands of: 1°/sec, 2°/sec, 4°/sec, 8°/sec, and 16°/sec each in alternating opposite (left/right) direction. The blue curve shows the resulting bank rate of APOLLO's FBW Airbus A320 over time. After a short rise time, the blue curve reaches the red sidestick input signal. Up to 10°/sec the APOLLO A320 behavior is pretty close to a real Airbus airplane. The green curve shows the real bank angle. The linearity of the green bank angle curve is caused by the precise conformity between the input and output bank rate commands.

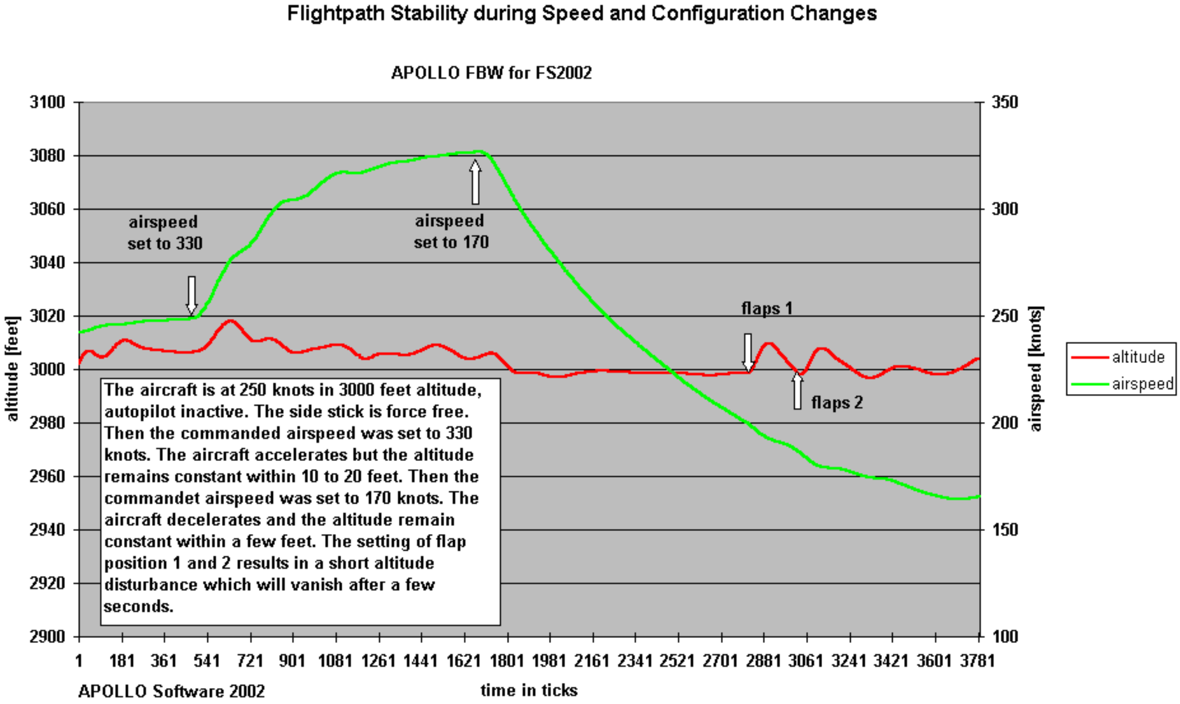
The following diagram shows the function of the APOLLO FBW g-load controller software implementation for FS2002. Again, the red curve shows the pilot's sidestick input. The following alternating positive and negative g-load values were commanded: +0.2, -0.2, +0.29, -0.35, +0.41, -0.5, +0.6, -0.72, +0.86, -1.01, +1.24 equivalent to effective loads of 1.2, 0.8, 1.29, 0.65, 1.41, 0.5, 1.6, 0.28, 1.86, -0.01 and 2.24 g. The dark blue curve shows the effective additional load factor g –1 (pilot input). After only a short rise time with a minimal overshoot the input value is reached and maintained, The green curve shows the pitch angle, alternating according to the g-load value. The linearity of the green pitch curve shows clearly that the transient oscillation of the software controller does not affect the flight of the aircraft.

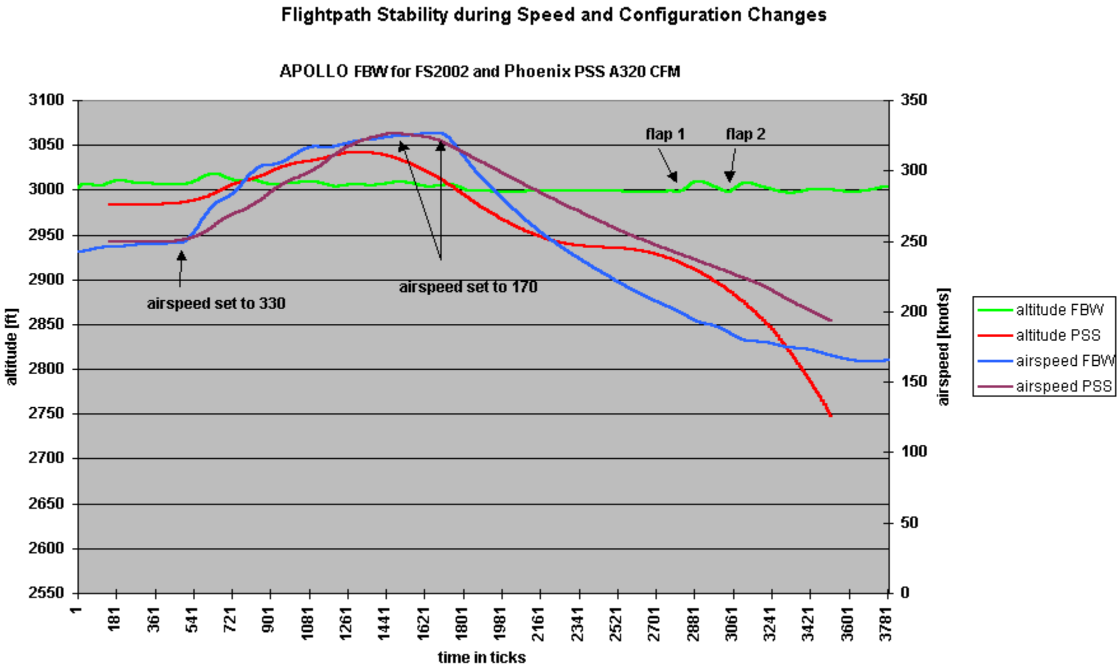


The following typical flight maneuvers illustrate the function of APOLLO's FBW Airbus for FS2002.

Flight path stability under speed and configuration changes

In the following diagram, the FBW Airbus is cruising in 3.000 feet altitude, at 250 knots. Altitude is shown in red, speed in green. Now a new speed of 330 knots is selected, and the green airspeed curve rises gradually while altitude is kept constant at 3.000 feet, except for a small transient oscillation of less than 20 feet! (the altitude scale is on the left of the diagram). After the new speed of 330 knots has been reached, the pilot now selects a new lower speed of 170 knots in the FCU (Flight Control Unit). Airspeed gradually decreases to the new value of 170 knots, and again the APOLLO FBW control software keeps the altitude perfectly constant at 3.000 feet. Finally, the pilot sets flaps 1 and 2, causing a short altitude deviation of less than 10 feet, which the APOLLO FBW software quickly compensates back to maintain 3.000 feet. Now compare this with the next diagram, showing the same maneuver, but this time flown with the Phoenix PSS Airbus. Altitude of the PSS Airbus is shown in red, speed in magenta. While speed characteristics between APOLLO's and PSS Airbus are similar, the PSS airbus fails this test, because it can not hold altitude but descends instead.

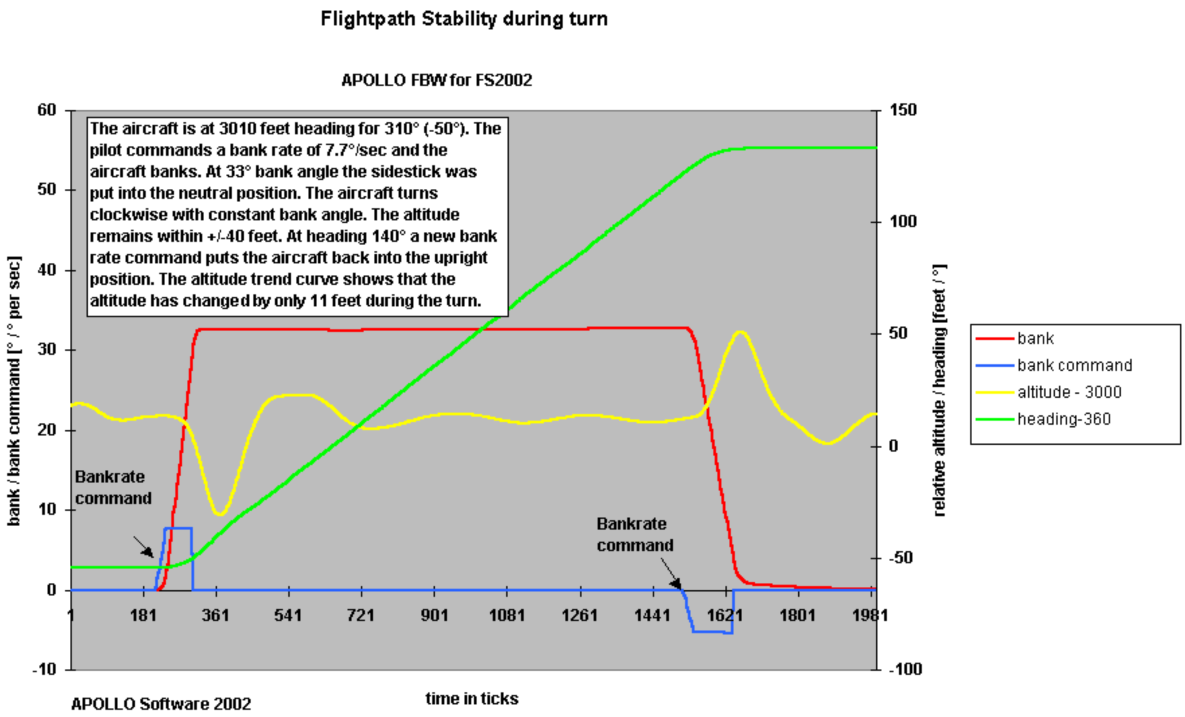


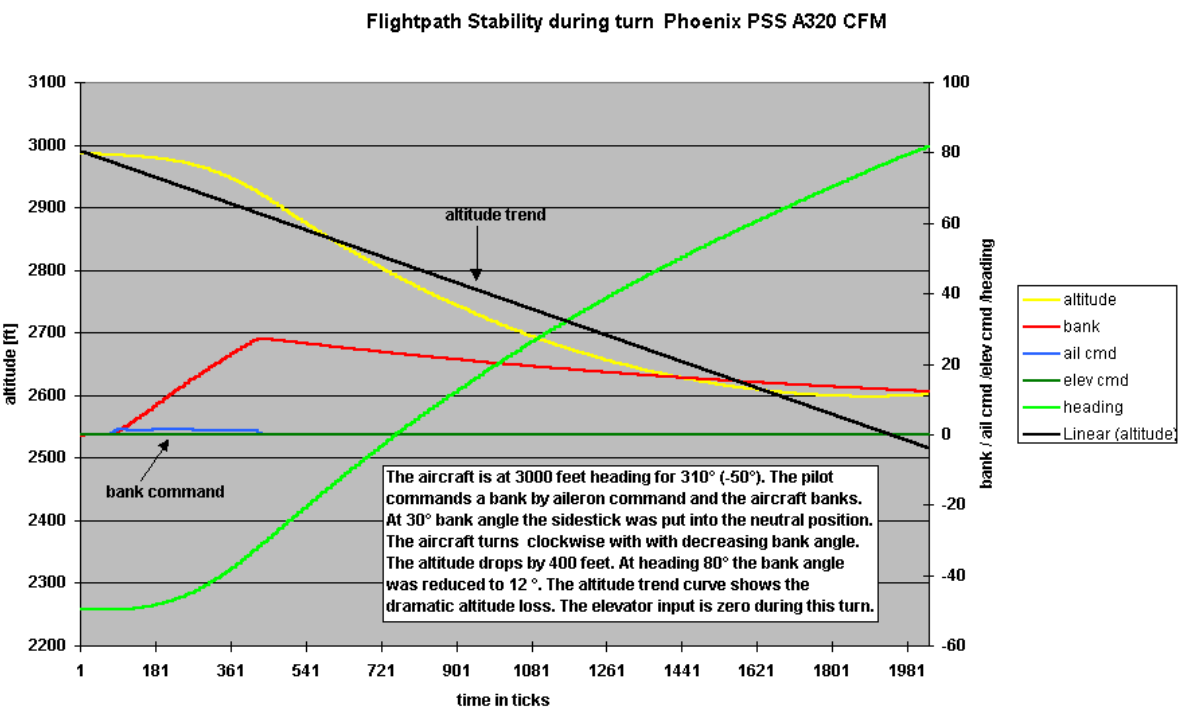


Flight path stability during turns

The following diagram shows the APOLLO FBW Airbus performance during turns. We'll begin again flying at 3.000 feet at 250 knots indicated airspeed. Altitude is shown in yellow, heading in green. Pushing the sidestick momentarily to one side issues a bank rate change command (blue curve) resulting in an immediate change of the bank angle (red curve). After releasing the sidestick, it moves back into neutral, maintaining the current value, in this example ca. 33 degrees of bank, which makes the aircraft turn smoothly (green curve = linear heading change). The slight altitude deviation at maneuver entry is immediately compensated for by the APOLLO FBW control software to maintain the initial altitude. After reaching a heading of 140 degrees, the pilot pushes the sidestick shortly in the opposite direction to put the airplane back into straight and level flight again. At the end of the maneuver, the altitude is the same as it was at maneuver entry, and maximum altitude deviation during the maneuver was less than +/- 40 feet.

The very same maneuver in the Phoenix PSS airbus will show a completely different result: the bank angle (red curve) increases constantly over time. But after releasing the sidestick back again into neutral position, the airplane recovers from its banked attitude! Therefore it can not change its heading (green curve) at a constant rate. At the same time, the PSS airbus looses some 400 feet altitude during the maneuver. Such a maneuver, if flown so badly by a „professional" airline transport pilot would result in him not qualifying for a commercial pilot license, and could even mean a pilot seeking only a private pilot license (PPL) „flight test fails".

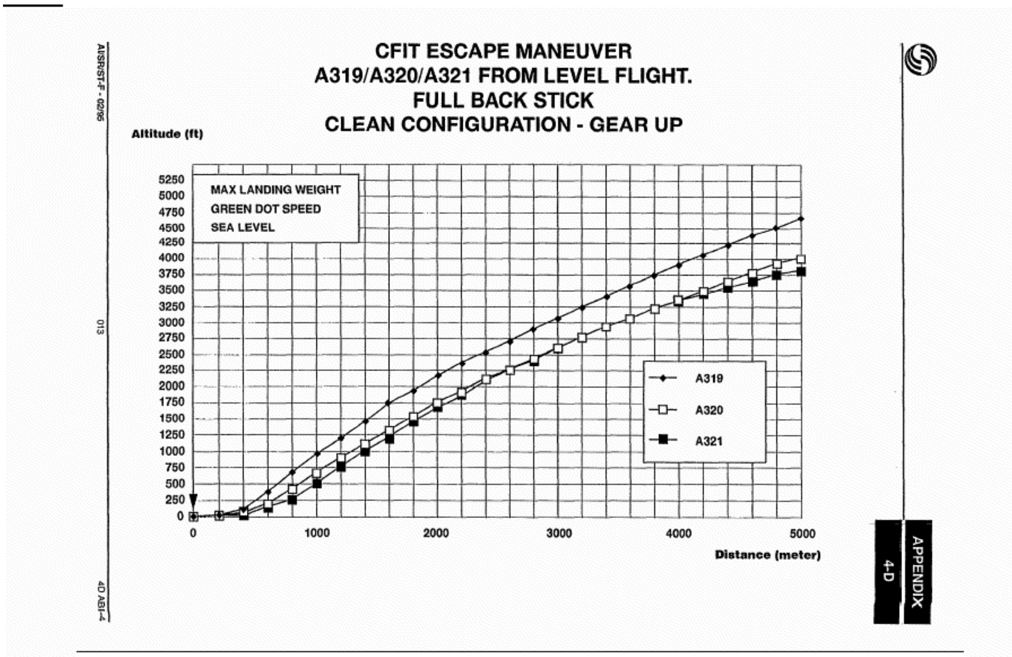




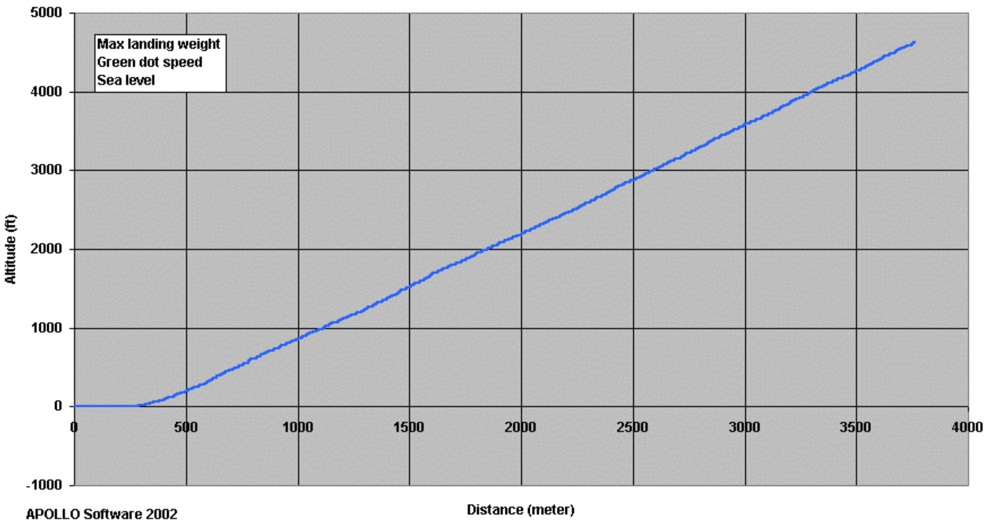
CFIT-maneuver (Controlled Flight into Terrain)

During the following flight maneuver we will begin with straight and level flight, then abruptly pull the airplane up as much as possible, and climb using maximum power to gain maximum altitude in the shortest time, to avoid an imminent impact on terrain (mountain), or to avoid other aircraft ahead. The challenge for the pilot in a conventional aircraft is to manually find the maximum climb rate while at the same time avoiding to stall the aircraft at its maximum angle of attack. If the aircraft enters a stall, the pilot would have to immediately lower the nose and therefore would loose some altitude during this maneuver to gain airspeed, which could result in CFIT. Not so in a FlyByWire Airbus with **Flight Envelope Protection,** which allows the pilot to pull the sidestick completely back and climb using maximum climb rate without ever stalling the airplane! The modern control mechanism of the Airbus FlyByWire technology is more precise and works more efficient than a human pilot ever could, especially under stress, at night or with no visual references on the outside world.

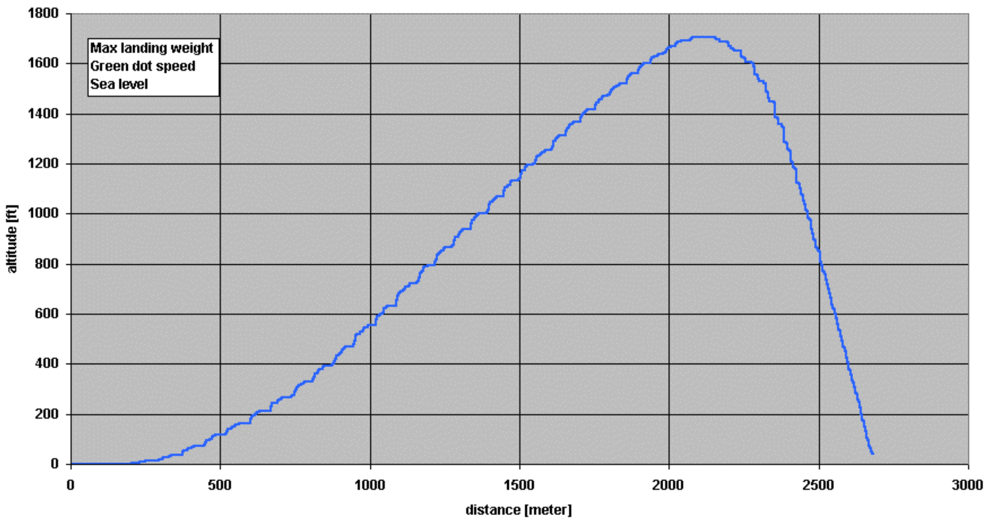
The next diagram shows real world data of the Airbus A319, A320 and A321, captured from real flight tests conducted by Airbus Industries. The diagram below shows data for the same maneuver captured using APOLLO's FlyByWire Airbus under Microsoft FlightSimulator 2002. The last diagram shows that the Phoenix PSS Airbus again fails under this test and performs just like any ordinary aircraft **without Flight Envelope Protection,** entering a dangerous stall and could crash under the CFIT maneuver.



CFIT ESCAPE MANEUVER APOLLO FBW A320 for FS2002 FROM LEVEL FLIGHT.
FULL BACK STICK CLEAN CONFIGURATION - GEAR UP



CFIT ESCAPE MANEUVER Phoenix PSS A320 CFM FROM LEVEL FLIGHT. FULL BACK STICK CLEAN CONFIGURATION - GEAR UP

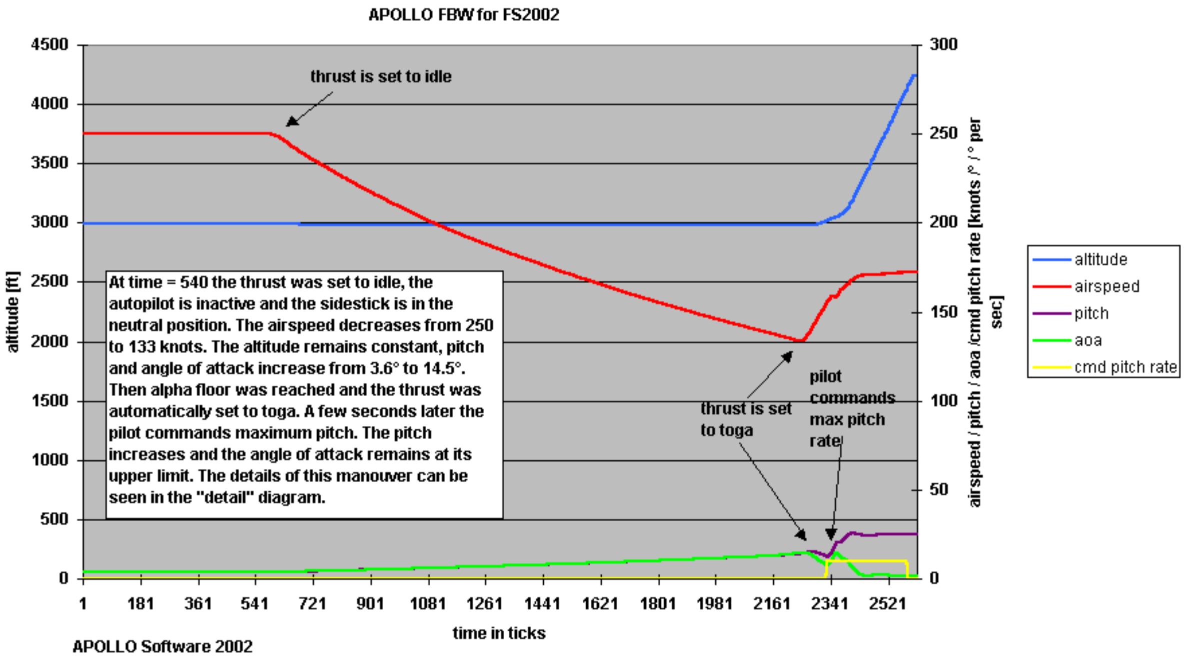


The next maneuver will demonstrate these characteristics in more detail. The APOLLO FBW Airbus flies level in 3.000 feet altitude at 250 knots. The autopilot is disengaged and the sidestick left in the neutral position. Then power is reduced to idle. What will happen now? Because the FlyByWire control tries to maintain the flight path vector, it must maintain altitude even as speed (red curve) decreases. As expected, airspeed will decrease, and APOLLO's FBW software will still keep the FS2002 Airbus at a constant altitude. This was to be expected, knowing the built-in software-based control characteristics. The angle of attack (green curve) is increased to compensate the loss in lift, caused by the speed decrease.

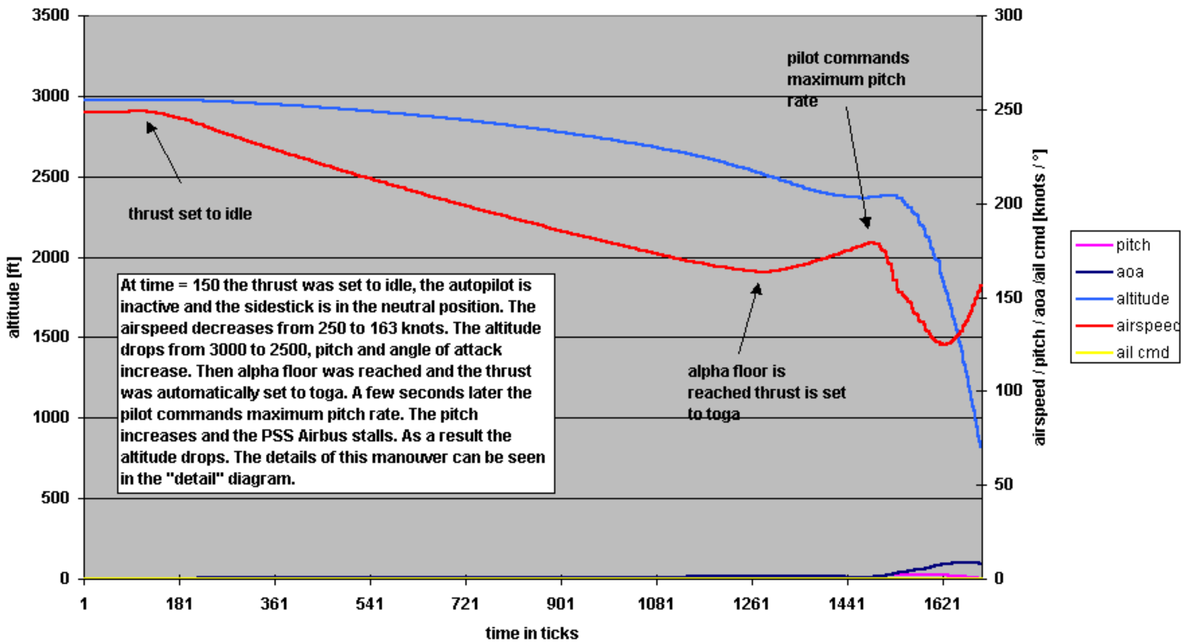
The angle of attack decreases further until it reaches the critical low value of "α floor" where thrust is automatically set to TOGA (Take Off - Go Around). Now airspeed will increase again and a further increase of the angle of attack is prevented to avoid the dangerous stall situation, while still maintaining a constant altitude. To make things worse, the pilot now pulls the sidestick all the way back, thus commanding the maximum climb rate. The pitch angle (magenta curve) increases up to 25 degrees while the angle of attack remains just above it, near α floor. After pitch remains fixed at 25 degrees, the angle of attack decreases back to non-critical values, and the Airbus begins to climb with full thrust and maximum pitch.

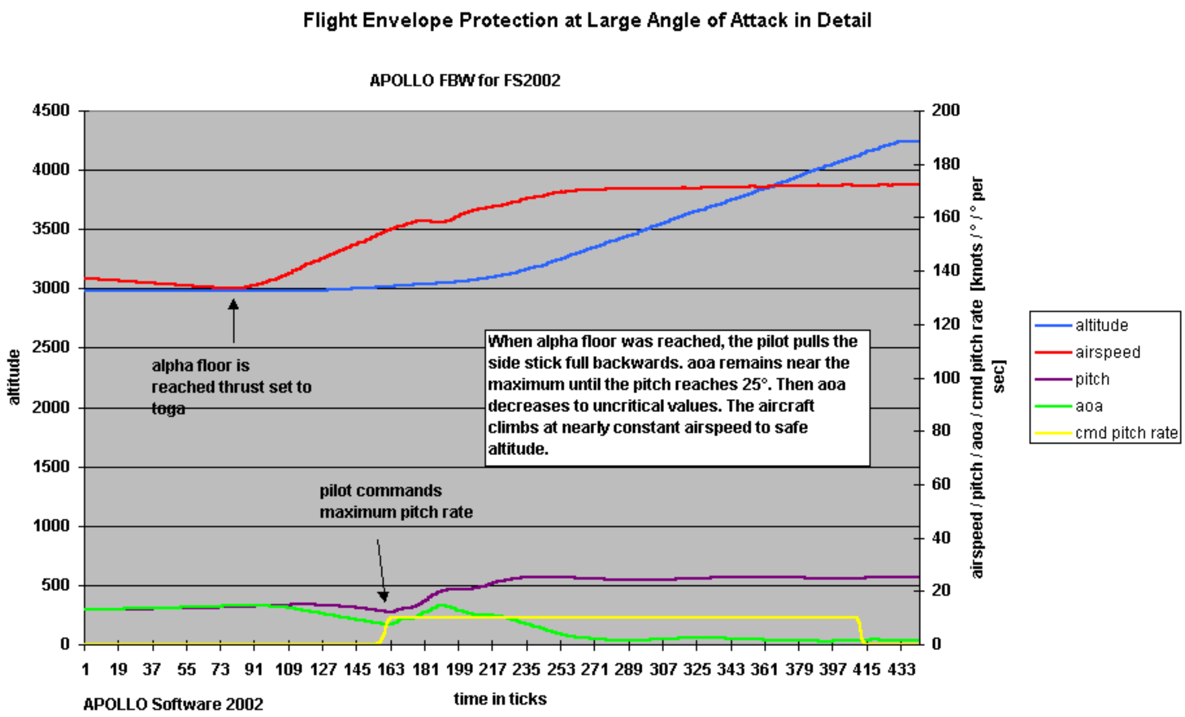
The diagram below shows the same scenario, this time using the Phoenix PSS Airbus. Initially, airspeed decreases here as well, BUT at the same time the airplane looses altitude until the plane reaches α floor, at which time thrust changes here as well automatically to full power, TOGA mode. Speed and altitude increase again slightly. Now the pilot pulls the sidestick all the way back: the angle of attack increases with no limitation, speed decreases for a moment, then the plane enters a stall, descends and looses altitude dramatically. This is illustrated again in more detail in the following diagrams.

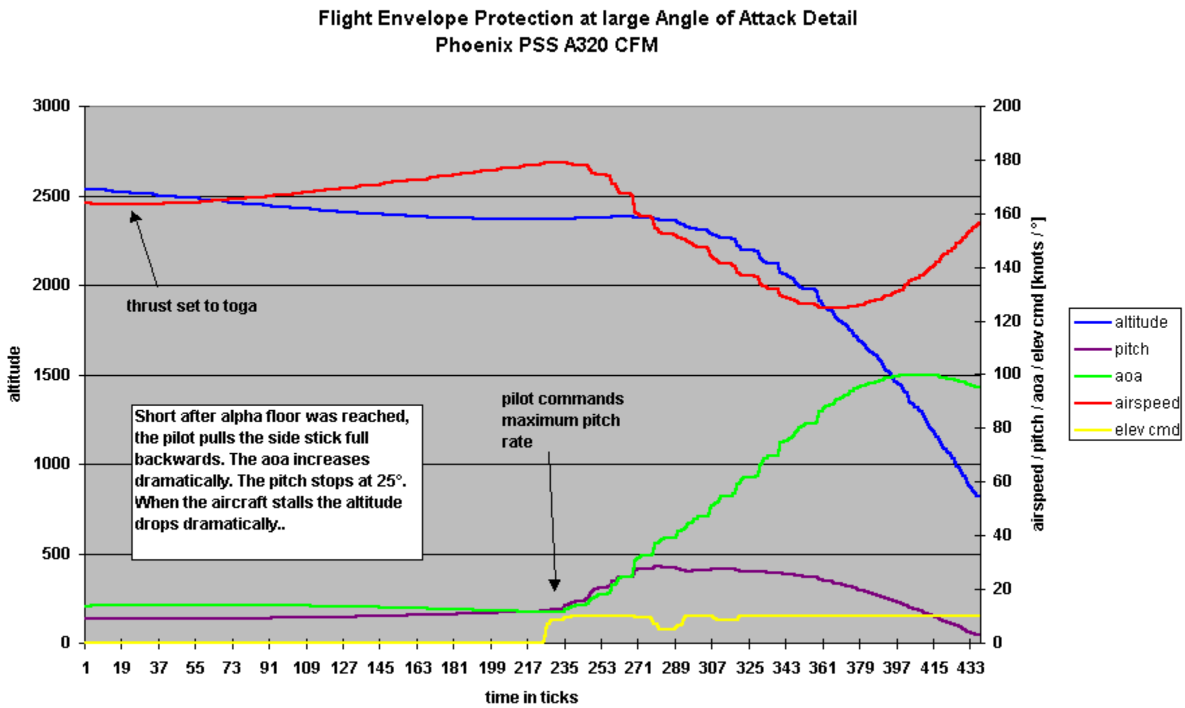
Flight Envelope Protection at Large Angle of Attack



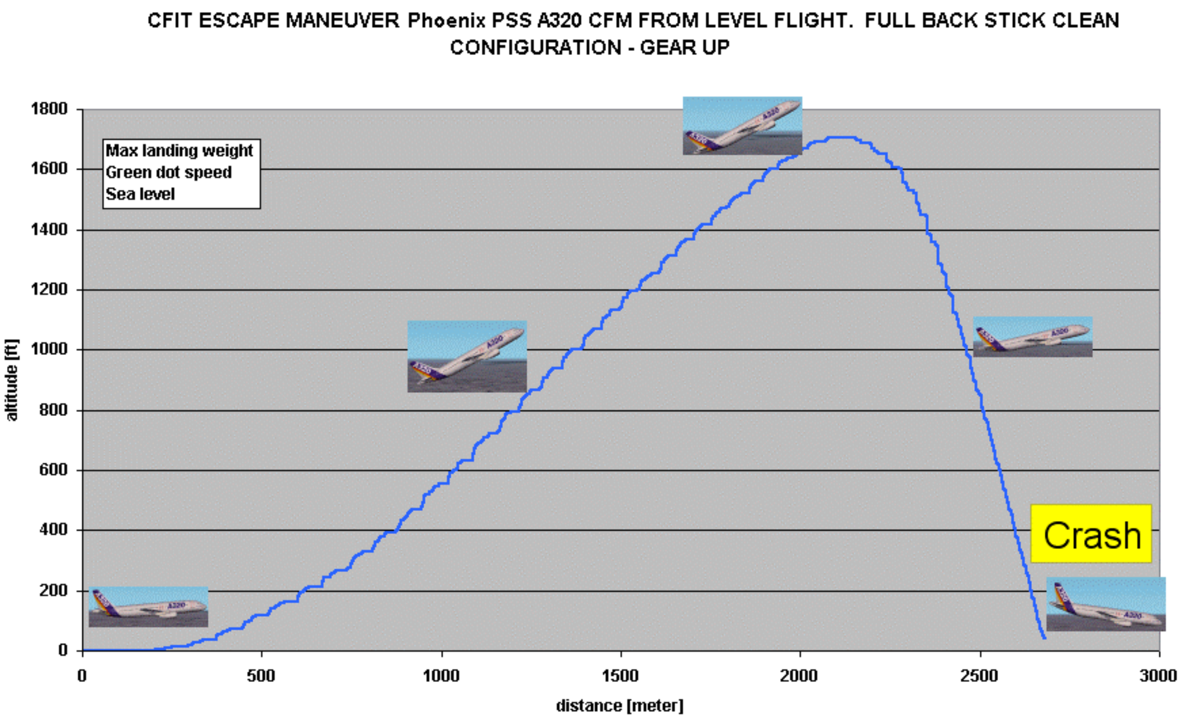
Flight Envelope Protection at Large Angle of Attack Phoenix PSSA320 CFM



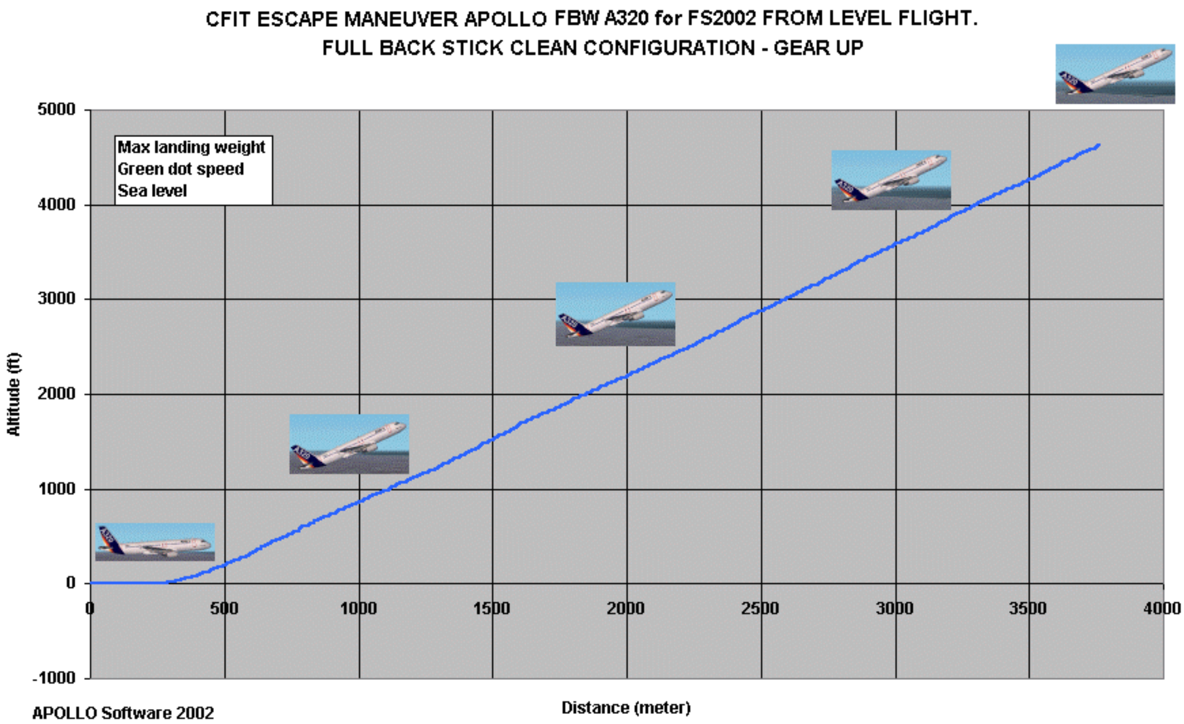




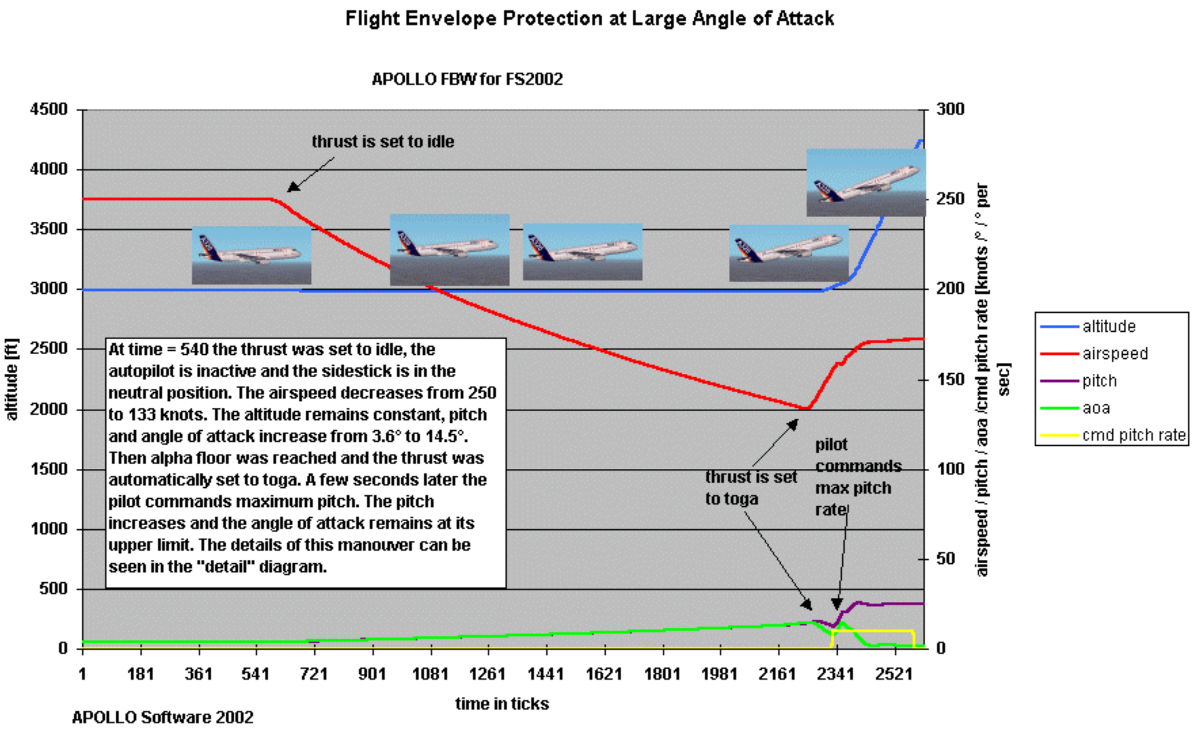
In the diagrams below aircraft symbols are attached to the displayed curves to demonstrate the aircraft behavior. This diagram is similar to the third image in diagram **CFIT**, with airplane symbols added to it.

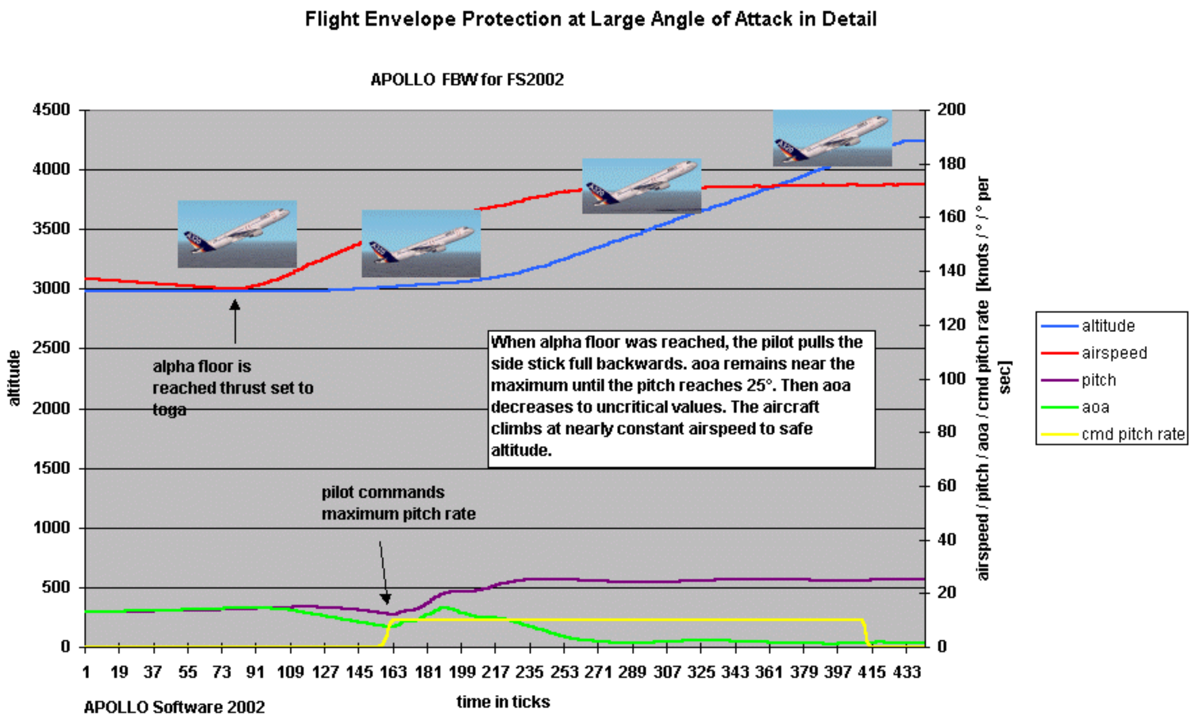


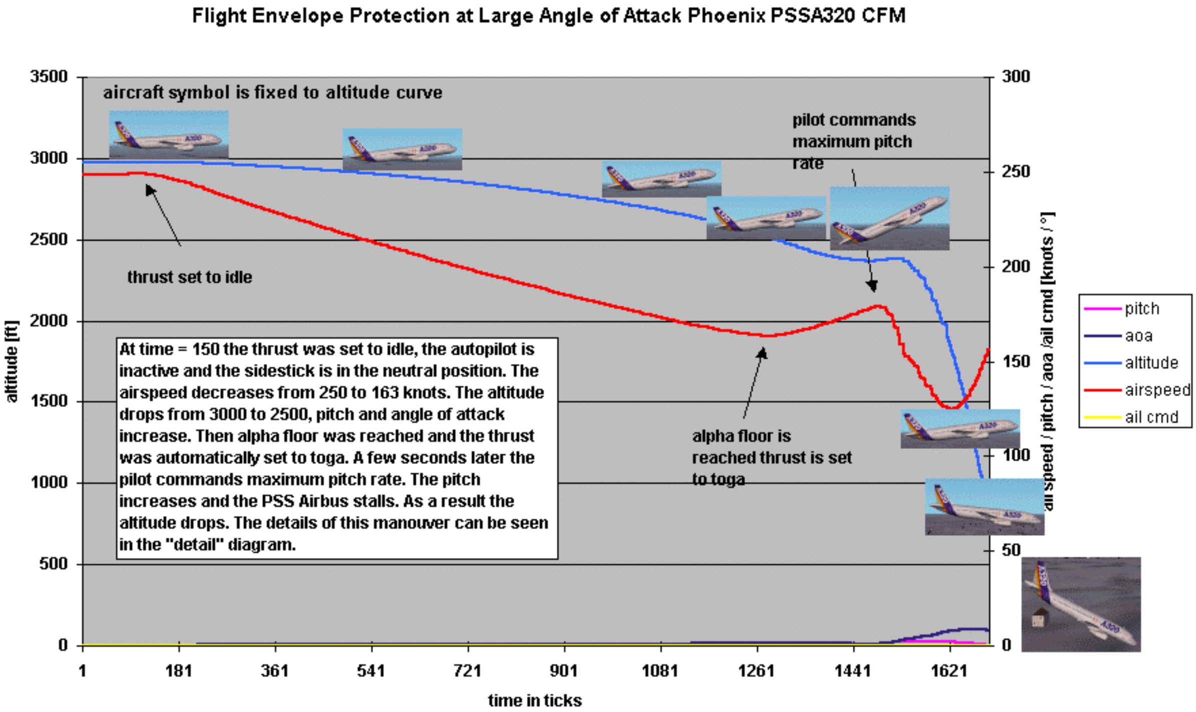
This diagram is similar to the second image in diagram **CFIT**, with airplane symbols added to it.

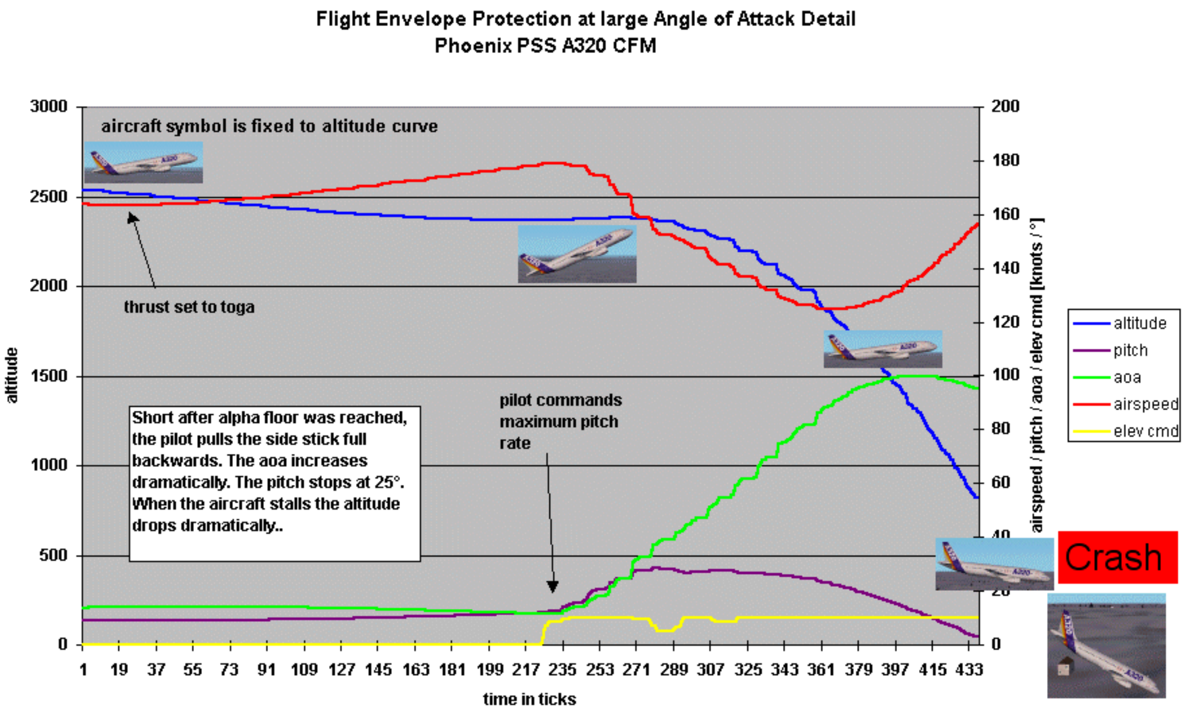


The following diagrams are similar to the flight envelope protection at large angle of attack diagramms, with airplane symbols added to it.


Flight Envelope Protection at Large Angle of Attack
APOLLO FBW for FS2002
thrust is set to idle
At time = 540 the thrust was set to idle, the autopilot is inactive and the sidestick is in the neutral position. The airspeed decreases from 250 to 133 knots. The altitude remains constant, pitch and angle of attack increase from 3.6° to 14.5°. Then alpha floor was reached and the thrust was automatically set to toga. A few seconds later the pilot commands maximum pitch. The pitch increases and the angle of attack remains at its upper limit. The details of this manouver can be seen in the "detail" diagram.
thrust is set to toga
pilot commands max pitch rate
altitude [ft]
airspeed / pitch / aoa /cmd pitch rate [knots /° / ° per sec]
time in ticks
APOLLO Software 2002
altitude
airspeed
pitch
aoa
cmd pitch rate


Flight Envelope Protection at Large Angle of Attack in Detail
APOLLO FBW for FS2002
alpha floor is reached thrust set to toga
When alpha floor was reached, the pilot pulls the side stick full backwards. aoa remains near the maximum until the pitch reaches 25°. Then aoa decreases to uncritical values. The aircraft climbs at nearly constant airspeed to safe altitude.
pilot commands maximum pitch rate
altitude
airspeed / pitch / aoa / cmd pitch rate [knots / ° / ° per sec]
time in ticks
APOLLO Software 2002
altitude
airspeed
pitch
aoa
cmd pitch rate





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