Appendix E

Gulf Air Flight GF-072 Perceptual Study
23 AUGUST 2000
Gulf Air Airbus A320-212 (A40-EK)
NIGHT LANDING

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Aircraft data from the FDR that influences spatial orientation were analyzed and evaluated at NAMRL at the request of the NTSB, POC: Bart Elias, eliasb@ntsb.gov.

Summary

This mishap represents a tragic, but scientifically interesting, accident in which a series of events led to a physiologically normal misperception of pitch orientation by the pilots in control of the aircraft. Due in part to the compelling nature of this false information, and in part due to the task saturation created by multiple cockpit distractions, the pilots did not perceive the true attitude of the aircraft. Indeed, based on our model of the pilots' perception of pitch up, the pilot in command provided inputs that resulted in further pitch down changes resulting in impact with the water.

Detailed Report

The perceptual model used to develop this report is built upon 60 years of research conducted primarily at NAMRL and supported by other labs around the world using a collection of ground-based acceleration devices and in-flight aircraft experiments to corroborate and extend the model. This model predicts the perceived orientation of pilots in response to acceleration conditions experienced in the aviation and space environments. The model assumes that the pilot is not receiving visual attitude information.

Background

Normal perceived orientation is based primarily on information from the senses of vision, inner ear organ of balance (vestibular system) and our skin-muscle-joint (somatosensory) receptors. All provide accurate, concordant, redundant orientation information in our day-to-day terrestrial activities. The problem occurs in the aeronautical environment where two of these systems (vestibular and somatosensory systems, collectively referred to as the "seat-of-the-pants" sensation by pilots) provide false but concordant, and hence compelling orientation information every time the aircraft is in any other condition but smooth, straight-and-level flight.

It is only with visual orientation cues that pilots overcome the illusions created by the seat-of-the-pants sensations, and even then not always. Whenever visual orientation information is absent, the brain continues to compute orientation with the only information available, namely the continuous information from the vestibular and somatosensory systems.

Physical Forces Producing Pitch Up Sensation

There are many in-flight forces that can produce a sensation of pitch up. It was an unfortunate condition of this flight that the pilots of Gulf Air 072 were exposed to several physical factors all acting in concert and some synergistically to produce a significant false pitch up sensation of approximately 12 degrees when in reality the aircraft was only pitched up 5 degrees (Figure 1, upper left, Perceived Pitch).

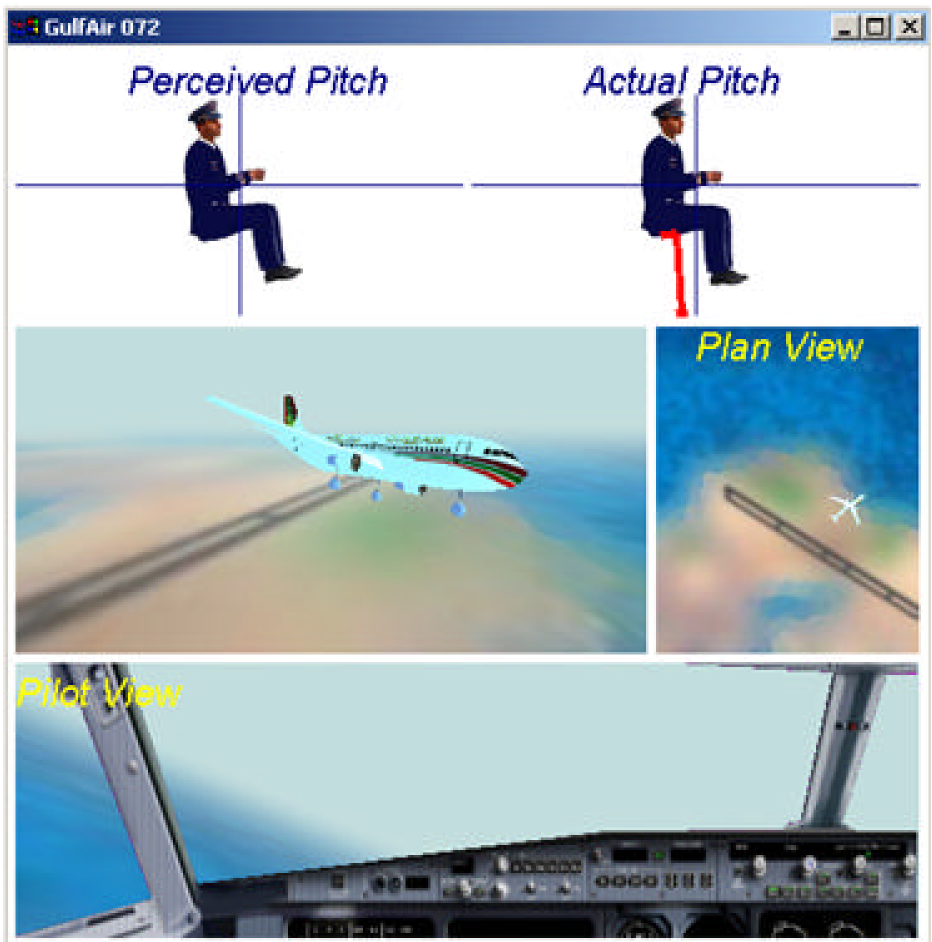

Figure 1: Perceived Pitch versus Actual Pitch just prior to stick forward (t=1929:43)
(Red Arrows in Actual Pitch panel are the Gx and Gz acceleration vectors)

The following forces contribute to the increased pitch up sensation.

1) The aircraft was linearly accelerating from the beginning of the second go-around maneuver (t= 1929:07s) until impact (Figure 2, Gx). This contributed to changing the direction of the resultant force vector from directly in-line with the vertical torso of the pilot to a rearward direction (Figure 4, blue arrows). This force contributes to the somatogravic illusion, a misperception of attitude that results in frequent mishaps. There is a time lag associated with this perception and so the time of loss of visual orientation cues is important. A secondary effect of the maintained linear acceleration is to increase the magnitude of the overall resultant vector (gravito-inertial force (GIF)), which contributes to the G-excess effect.

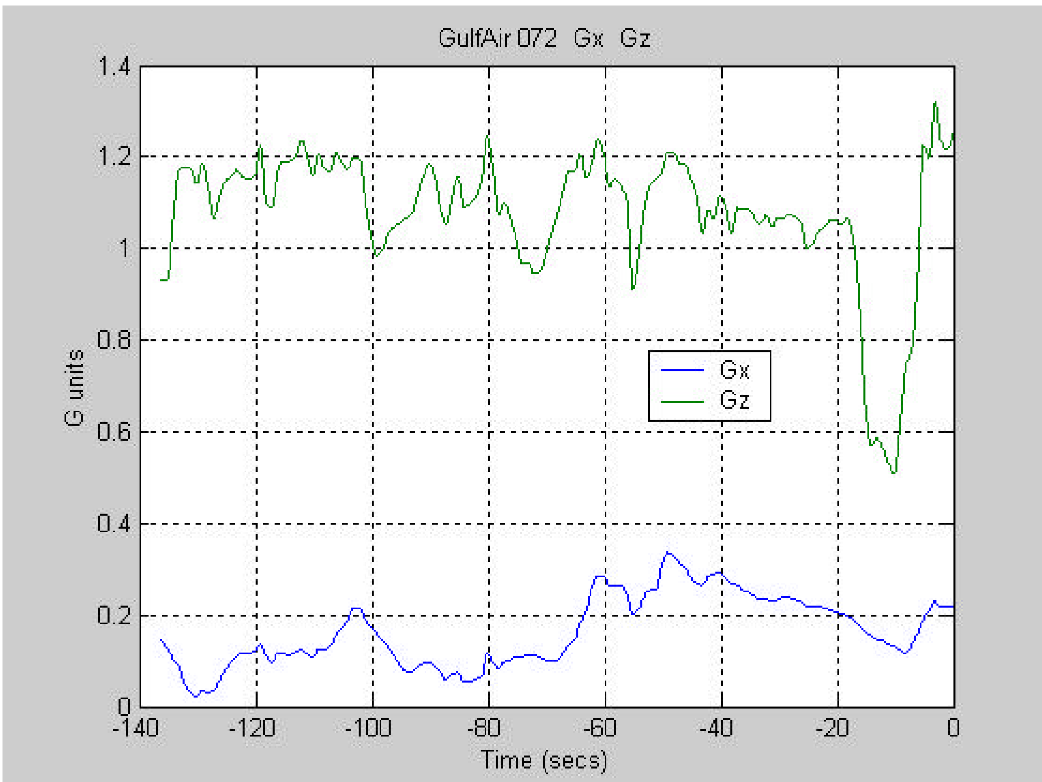

Figure 2: Gx and Gz Forces versus Time to impact

2) The angle of bank of the aircraft increases the magnitude of the resultant force vector (and even more so when vertical velocity was increasing as in this mishap). This force contributes to the G-excess effect (Guedry et. al, 1972) and results in an increased perception of pitch up. The magnitude of the pitch up percept depends on the increase in the GIF and on head position. In this mishap we are assuming that the pilot has his head inclined slightly downward by about 15 degrees that reduces the magnitude of the pitch up percept. As with the somatogravic illusion there is a time lag in both the onset and offset of the perception following application of the increased "G" force. This is factored into the dynamics of the perceptual model.

3) The rate of climb after the initiation of the second go around results in a mild but maintained vertical acceleration that contributes to an increase in the overall resultant force vector.

4) Angular acceleration due to changes in aircraft pitch synergistically affects the somatogravic pitch illusion when the angular acceleration acts in the same direction as the somatogravic pitch illusion. On the other hand, strong linear acceleration can block the affects of the angular displacement (McGrath, 1990). In this mishap, the overall resultant force vector was rapidly decreasing in magnitude at the same time the aircraft pitched down resulting in a pitching forward perception (Figure 3). This explains why in Figure 3 the perceived pitch sensation does NOT follow the GIF angle. The preceding turn associated with the second go around contributes to this difference in two ways – first from the direct G excess pitch up and secondly by contributing to a larger change in the overall magnitude of the GIF.

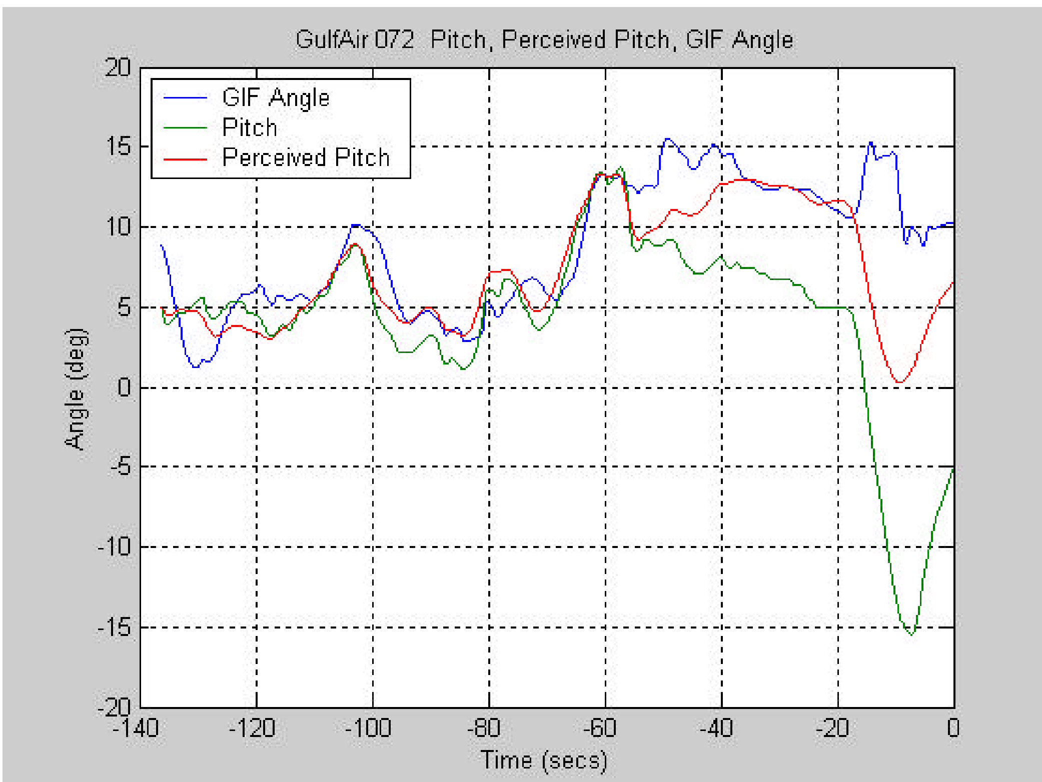

Figure 3: Pitch, Perceived Pitch, GIF Angle versus Time to Impact

The dynamics of the first three physical forces mentioned above are summarized in the time course plot (Figure 4) showing the magnitude of the resultant force vector (GIF) and the angle this vector makes with respect to the upright (head-to-seat) axis of the seated pilot. The only factor missing is the pitch stimulus associated with angular acceleration about the pitch axis (# 4 physical force above).

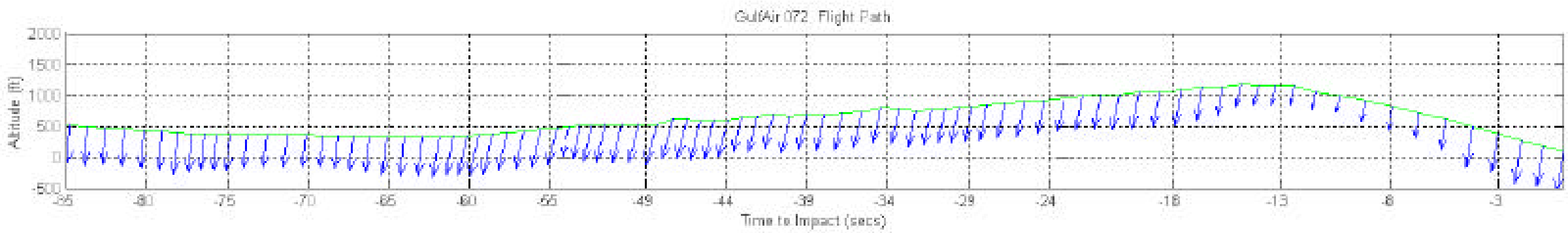

Figure 4: Flight Path of Gulf Air 072 versus Time to impact and Resultant Force Vector (GIF)

The overwhelming nature of the pitch illusion is evidenced by the fact that the pilot in command did NOT follow the recommended GPWS procedure of "Pull up to full back stick and maintain", since he believed he was approximately level and so only partially pulled the stick, (Figure 5; i.e. he pulled to approximately 11.7 degrees aft vice the maximum capability of 16 degrees aft, Figure 6)

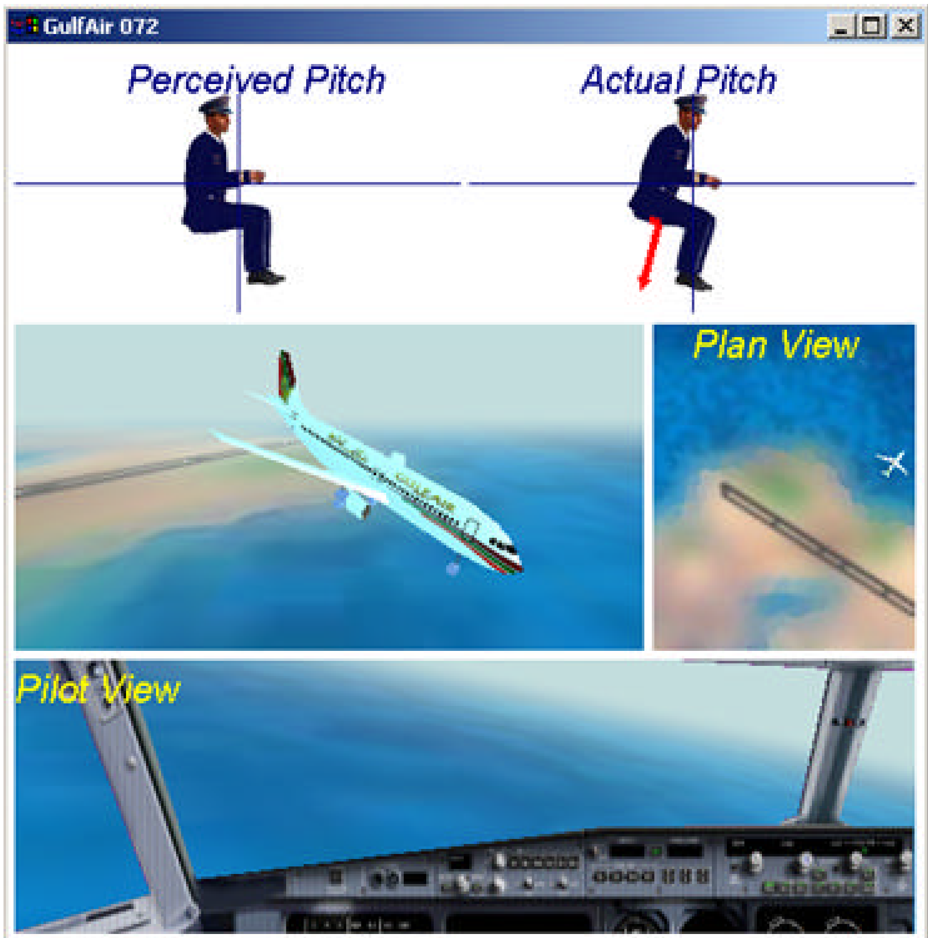

Figure 5: Perceived Pitch versus Actual Pitch just prior to stick back (t=1929:53)

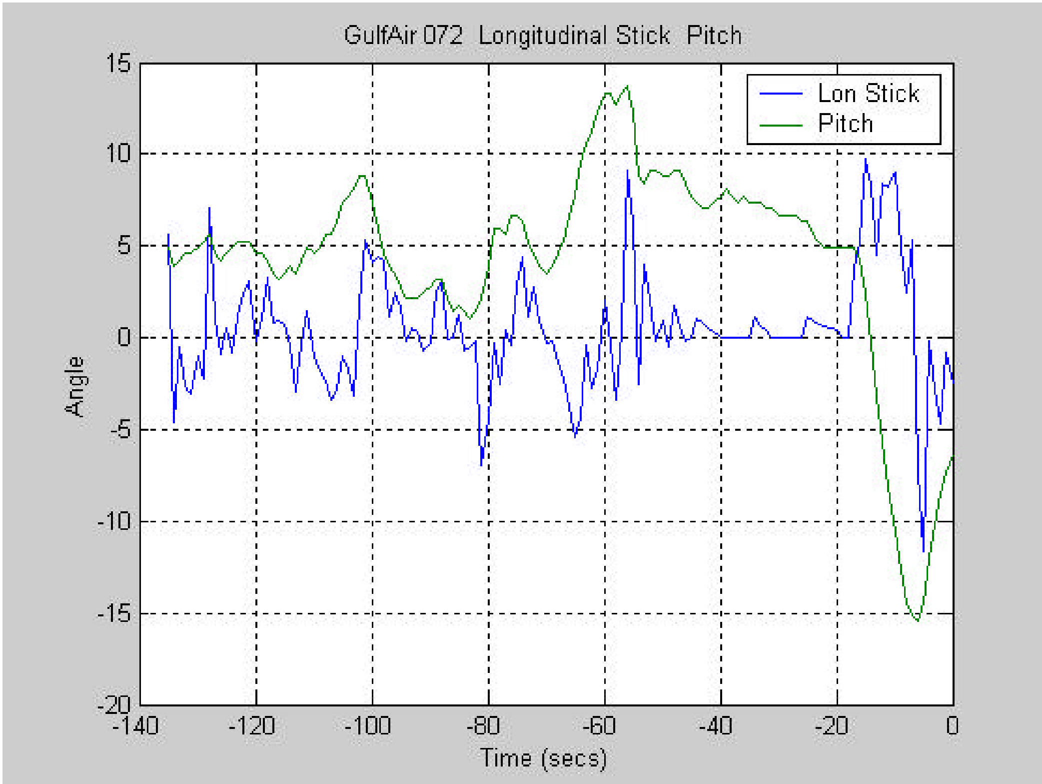

Figure 6: Pitch, Longitudinal Stick Position versus Time to Impact

An important factor in predicting the perception of the pilot is determining the point at which the pilots no longer are attending to, or receiving, accurate outside and inside orientation cues. This is addressed in the following section.

Time of Loss of External Visual Orientation Cues

Given the altitude, night visibility conditions and the available view from the cockpit, the NAMRL video reconstruction places the time at which the pilot could not obtain visual cues from looking outside as approx 21 sec before impact (Figure 7, t=1929:41). However, we believe that the pilot in command from the beginning of the second go around (t= 1929:07) until impact had his FULL attention directed inside the cockpit. From the point at which he instructed the first officer to inform ATC of his intention to make a second go around until impact he was attending to power application, then flaps, then landing gear, aircraft heading issues and finally other multiple in-cockpit actions required to deal with master warnings associated with overspeed and sink rate. Despite the presence of the primary flight display (PFD) we assume that the pilot was NOT allocating attention to the PFD. Both PFDs are located outboard on the cockpit instrumentation panel and the location of the items to which the pilot was attending from the point of the second go around are centrally located and most are in the center of the cockpit.

Establishing the time of the second go around as the point at which the pilot was fully absorbed with in-cockpit tasks is of significance to the perceptual model for several reasons: – first the highest angle of bank occurs at this point and the G excess effect contributes to the early portion of the pitch up sensation, thereby “setting the stage” for the somatogravic illusion; secondly, the go around is associated with other physical forces mentioned in the above section. These forces have a synergistic influence on perceived pitch during the final 18 seconds when the GIF influence on the pitch sensation decreases as the canal input from the pitch forward comes into play.

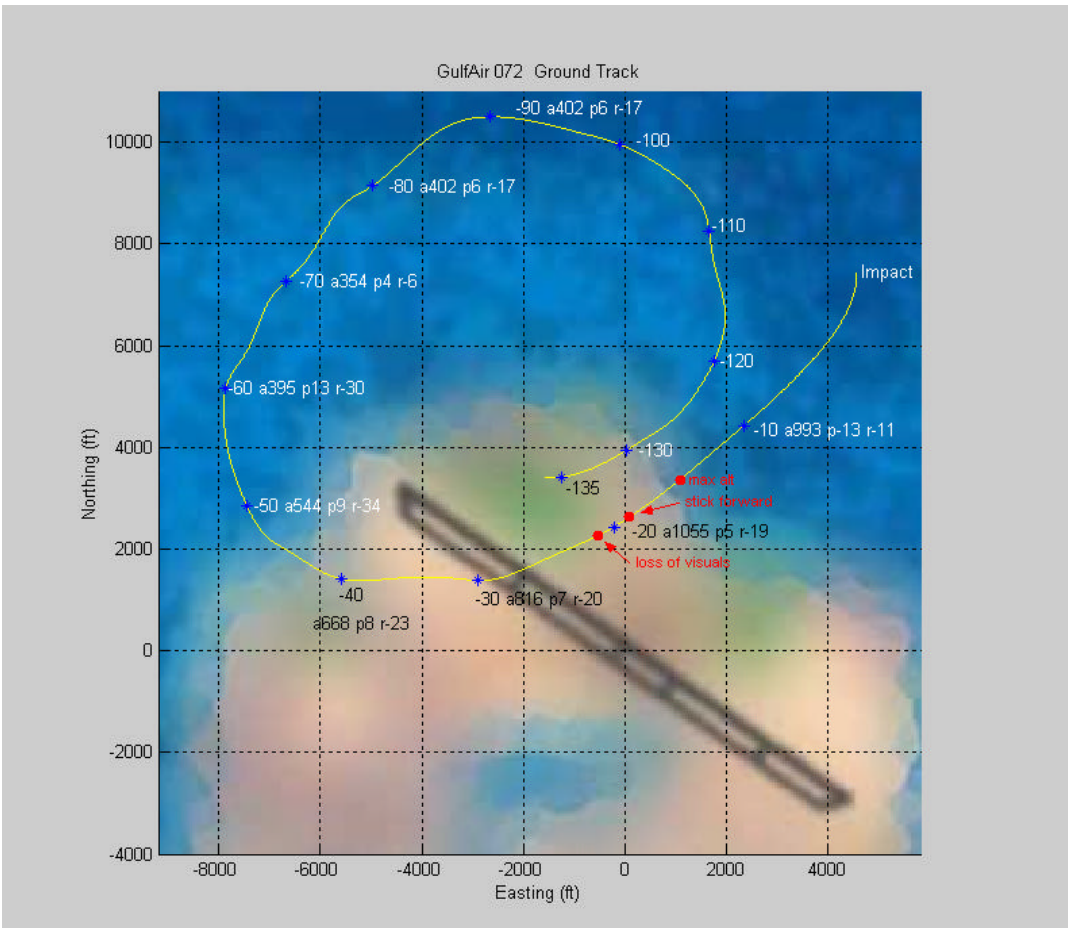

Figure 7: Flight Path (time to impact, altitude, pitch, roll)

Workload Issues

There are a multitude of factors that have been addressed by many human factors experts such as – tunneling of attention, task saturation, novelty of events and so on. There is little doubt that a chain of events is involved in this mishap - the pilot was too high leading to the first unsuccessful approach; the 360-degree orbit not achieving expected result; the probability of geographic disorientation as evidenced by the first officer calling out “runway in sight” and the pilot in command taking about ten seconds to perceive and remark “we overshot it” while dealing with a relatively inexperienced first officer and feeling the need to “do it all”; and a first officer who had to deal with several novel unexpected conditions. ALL of these factors were superimposed on a strong illusion created by several physical forces acting in concert. This assists in explaining why neither pilot directed sufficient attention to the PFD.

In the military we work on several such mishaps EVERY year. The conclusion of the mishap board is generally the same – “the pilot failed to maintain a proper instrument scan”. Unfortunately, this has NOT reduced the frequency of these mishaps. A recent trend in higher-level endorsements has been the inclusion of recommendations for software solutions, new displays that provide continuous non-visual information, and improved training.
