(Photos courtesy National Transportation Safety Board)

On December 8, 2005 Southwest Airlines flight 1248, a Boeing 737-700 class jet with 103 persons aboard, attempted to land on a snow-covered runway at Chicago's Midway Airport. Tragically, the attempt resulted in the death of a child on the ground, as the plane slid far enough beyond the runway to leave airport property and collide with a car (in which the child was a passenger) on the road beyond. Both the analysis *and prevention* of accidents such as this rely on the kinematics of one-dimensional motion. In this problem we will examine how the National Transportation Safety Board (NTSB) arrived at the conclusion that "the probable cause of a fatal runway overrun...was the pilots' failure to use available reverse thrust in a timely manner to safely slow or stop the airplane after landing." (NTSB press release SB-07-48)

The NTSB report does not give the full range of data available to the official accident investigators, but it does yield enough details to make a basic check of their findings. According to the information released to the public, the plane touched down with 4576 feet of regular runway remaining and an 82 foot runway safety overrun area beyond. The plane was moving at a ground speed of 131 knots when it touched down. Brakes were employed essentially immediately, but the pilots failed to completely reverse the engine thrust until 18 seconds after touchdown (for comparison, four of the five air carrier airplanes landing in the 25 minutes prior to the accident reversed engine thrust within 4 seconds of touchdown, and all did so within 6 seconds). At approximately 29 seconds after touchdown the plane left the back of the runway safety area moving at a ground speed of about 53 knots.

a.) Assume that the plane experienced two different but constant accelerations during its progress down the runway. The first acceleration (a_1) resulted from application of the brakes with no help from reverse engine thrust and was experienced for 18 seconds. The second acceleration (a_2) resulted from the application of the brakes plus the reverse thrust and was experienced for the remainder of the 29 seconds the plane was on the runway. Determine the magnitude of these accelerations.

b.) We can get an idea of how our assumptions compare with those used by the investigators. The NTSB investigators released an estimate stating that if the airplane had landed on an infinite runway so that the plane could just keep decelerating until it stopped, it would have come to rest about 790 feet beyond the point where the actual runway overrun area ended (in other words, the plane would have needed 5448 feet to stop if it had not encountered obstructions). How far beyond the end of the runway safety overrun area does our model predict the plane would have come to rest? Give your answer in **feet** to facilitate comparison.

c.) As a further comparison, the investigators stated that if reverse thrust had been employed through the entire trip down the runway (in other words, the reverse thrust was activated instantly upon landing instead of 18 s after touchdown), the airplane would have successfully stopped 230 feet short of departing the runway safety overrun. Using our model, what would you calculate for the remaining runway after stopping if reverse thrust had been used immediately upon landing?

Optional follow-up: Based upon your model, how quickly after touchdown would the pilots have had to reverse thrust in order to keep the plane on the runway?

Final note: If you read the accident reports (available on the web) you will see that the same kind of physics that we used here is actually routinely employed by Southwest Airlines pilots *before* landing using an on-board performance computer (OPC) in an attempt to prevent this kind of accident. The pilots of flight 1248 were apparently misled by their computer because it did not make two important assumptions about parameters clear. First, because of the poor weather, the computer assumed a maximum tailwind of 5 knots even though the pilots thought it was recognizing their (correct) input value of 8 knots. Second, the computer had already accounted for full reverse thrust in its calculations although the pilots thought that the computer had assumed zero reverse thrust. Prior to this accident, the Federal Aviation Administration (FAA) had allowed reverse thrust to be considered in these calculations for some airplane models but not for others (for example the Boeing 737-700 model of flight 1248 was allowed to consider reverse thrust even though other 737 models such as the 737-300 and 737-500 were prohibited from considering it). One of the NTSB's first acts resulting from the accident was to urgently recommend the removal of the so-called reverse thrust credit from all calculations of stopping distance. (NTSB Safety Recommendation A-06-16)