NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

August 27, 2008

ADDENDUM 3
TO THE

OPERATIONS / HUMAN PERFORMANCE GROUP

GROUP CHAIRMEN'S FACTUAL REPORT

DCA09MA021

BACK-DRIVE SIMULATION STUDY

A. ACCIDENT

Operator:	Continental Airlines
Location:	Denver International Airport, Denver, Colorado
Date:	December 20, 2008
Time:	1818 Mountain Standard Time
Airplane:	Boeing B-737-500, N18611

B. OPERATIONS / HUMAN PERFORMANCE GROUP

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C. FACTUAL INFORMATION

Operational factors / human performance group members and others observed a back-drive simulation of the accident sequence derived from flight data recorder data.

C.1. Description of the Back-Drive Simulation

Boeing provided the following information describing the characteristics of the back-drive simulation:

> The back-drive was created using the Boeing, multi-purpose engineering cab (M-Cab) to better understand what the flight crew experienced. The back-drive re-created the visual scene from the cockpit, flight control inputs, and aircraft accelerations based on FDR parameters.
>
> The M-Cab is a multi-use facility with the ability to change between different aircraft models. The shell is based on the 767, and so as a result, specific to this demonstration the tiller control and tiller position do not provide an exact

representation of the tiller configuration on the 737. As with all motion devices, the ability to produce sustained accelerations is limited to the available workspace. Techniques such as platform tilt are used to give the perception of sustained acceleration in the cab.

The cockpit visual scene consisted of a visual picture of the runway environment at DIA during the day and night, as well as an accurate representation of aircraft heading and ground track. A 737-500 with winglets was used for the visual representation of the aircraft during daytime. During nighttime demonstrations a 737-800 with winglets visual model was used for landing light capability.

M-Cab flight control inputs were back-driven using FDR pedal, wheel, column, and throttle handle positions. Participants were able to follow along with the flight control inputs; however, because the simulation was a back-drive there was not the usual representation of control forces. The back-drive did not allow for pilot interaction with the simulation.

The aircraft pilot seat lateral acceleration (Ny) was calculated from the FDR lateral acceleration, which is located near the aircraft CG. The M-Cab motion system was used to achieve a perceived Ny at the cockpit eye reference point that closely matched the aircraft pilot seat Ny.

Yaw acceleration, calculated from the FDR heading was also used to drive the M-Cab platform motion. It was not possible to match the magnitude of the aircraft yaw accelerations, while simultaneously achieving a good Ny match. The magnitudes were considered to be an acceptable representation of aircraft motion for purposes of the evaluation. Accurate timing of the yaw acceleration was considered to be of primary importance to reinforce the visual cues associated with heading changes.

C.2. Simulation Participants

Nine FAA-certificated pilots (six operational factors / human performance group members and three additional pilots from NTSB and Boeing) participated in the simulation. Some details about each participant are provided in table 1.

Table 1. Highest pilot certification held by each simulation participant.

Participant number	Highest pilot certificate	B-737 Type-rating
1	Private pilot	No
2	ATP	Yes
3	Commercial multi-engine instrument, CFI MEL	No

4	ATP	Yes
5	ATP	Yes
6	Private pilot	No
7	ATP	No
8	ATP	Yes
9	ATP	Yes

C.3. Participant Comments

Each participant observed the back drive from the left pilot seat as many times as they wished. Participants were allowed to adjust the endpoint of the simulation as they desired. Table 2 contains participants' comments from each run. The comments listed in table 2 were provided by the pilot in the left seat, unless noted otherwise. Trials are listed in order of presentation.

Table 2. Comments made by simulation participants.

Trial	Left Seat Pilot	Right Seat Pilot	Simulation End Time	UTC Equivalent End Time	Comments
1	7	8	740	1:18:18	[Day visual] Interesting. Rudder seemed okay until the end. Was trying to attend to the wheel. Would have preferred to have it in a bit faster.
2	7	8	740	1:18:18	[Day visual] Sure seemed like you could keep it on the runway.
3	7	8	740	1:18:18	[Day visual. Simulated a grab for the tiller.] I kept my right hand on the tiller because I was anticipating stopping the airplane, not continuing the takeoff. Had to make myself grab for the tiller.
4	7	8	740	1:18:18	[Night visual from this trial after.] Better with the night cues. More aware of the sensation of the airplane and its response. Felt normal at the beginning. Normal crosswind inputs, then looked like he just gave up at the end and quit making inputs.
5	7	8	735	1:18:13	Up to the stop point, what he was doing felt normal and just felt like he let go of the rudder a little bit.
6	7	8	731	1:18:09	It feels normal. A good bit of right rudder. He got back to the centerline and then let go. Looks like he was doing everything exactly right at that point. [Right seater: 40-45 degrees of left wheel in at the stop point.]
7	N/A				
8	7	8	735	1:18:13	That was a good one. You really have the sensation that he gave up on the rudder.
9	7	8	736	1:18:14	It seemed normal. Seemed like he could have kept it there. I never got the feeling he couldn't keep it on the runway. [Right seater notes that the wheel moved slightly to the right in the last second before the stop time.]

10	7	8	740	1:18:18	It feels like a normal crosswind takeoff. Then he just takes the control out. It does not feel like the airplane is out of control.
11	7	8	740	1:18:18	Feels normal. He just releases the rudder.
12	1	2	740	1:18:18	Giving it everything he's got, then seems to get scared or overwhelmed. [Right seater observation: The F/O was looking at the power. By the time he looked up the captain was already making large corrections.]
13	1	2	740	1:18:18	Rudder input almost full extension of my right leg.
14	1	2	731	1:18:09	Really big right rudder input. Dead on centerline. [Right seater: I agree, lot of rudder, right on centerline.]
15	1	2	735	1:18:13	Interesting that he backs off on right rudder as the nose is moving left.
16	1	2	733	1:18:11	[Observer, 8: Looks like he was controlling it until it veered left.] [Control loader malfunction.]
17	1	2	733	1:18:11	[Control loader malfunction, simulation aborted.]
18	1	2	733	1:18:11	Nose moving slightly left of centerline at peak of second rudder input.
19	1	2	733	1:18:11	Left motion starts before second peak input.
20	1	2	733	1:18:11	Does stop leftward motion after second input, but stops it left of centerline.
21	1	2	740	1:18:18	Can't seem to bring it back on centerline until after he has ramped the rudder up to the first full right input.
22	1	2	740	1:18:18	Heading oscillations do not look big until the big swerve.
23	1	2	740	1:18:18	The wind requiring the first full right rudder input seems to rattle him.
24	2	3	740	1:18:18	Felt like he had rudder in the whole time after the first input. [Right seater: You would feel it if in your leg muscles you were maintaining right rudder.]
25	2	3	740	1:18:18	[No comments.]
26	2	3	740	1:18:18	[Simulated grabbing the tiller at the end.] Feels like he does have rudder in as the airplane is veering left. Do not think he felt more right rudder would help.
27	4	3	740	1:18:18	He was tracking down the centerline. It veered left. The rudder was doing one thing and I was subconsciously trying to press right rudder. Never felt like I had full rudder pedal travel in this mockup. I feel like I have put that much rudder in momentarily during takeoffs I have performed in the airplane.
28	4	3	731	1:18:09	I just put in a half-travel right rudder pedal input and corrected back to the centerline.
29	4	3	733	1:18:11	I just made an application of rudder, now back into crosswind configuration. A little rudder, left wing down, nose was left of the centerline but tracking straight.
30	4	3	735	1:18:13	I didn't like it. Didn't feel like he made a lot of rudder input before it went left. The first large right rudder input was more noticeable. The second

					seemed a lot less. Now I'm neutral and the airplane is pointed left at 100 knots.
31	4	3	736	1:18:14	I feel uncomfortable right now. It's in a skid going sideways and I don't know why, but the rudders are neutral now. I had just made a rudder input to keep it on the centerline and it went left again.
32	4	3	740	1:18:18	[Simulated grabbing the tiller.] I subconsciously kept my right hand on the thrust levers.
33	4	3	736	1:18:14	I can't explain that. I don't know what would have caused the lack of rudder. The second rudder input didn't feel like it was that much. The first one felt like a pretty good right rudder input. [Observer question - when would you have rejected? Answer: If I had full right rudder in and it was still heading off the runway.]
34	4	3	731	1:18:09	This input didn't feel like a full right rudder input, but the second one [just before time 40] felt like quite a bit less.
35	3	4	740	1:18:18	I don't know why it took that rudder out. I feel the lateral G a lot more in the left seat. Feels light and squirrelly. Feels like I should have more rudder in and I have rudder authority remaining. Seems like throttle split is to help line up at the beginning.
36	3	4	740	1:18:18	Doesn't feel like I've lost control of the airplane just before it veers left. Feels like I want to push with my right leg.
37	3	4	740	1:18:18	Tiller does not feel like the right thing to do.
38	3	4	740	1:18:18	Did not feel like I had run out of control authority. Did not feel like rudder wasn't working.
39	3	4	735	1:18:13	I've got loads more to do with the right leg. Want to step on it like a second ago.
40	3	4	732.8	1:18:10.8	Did feel a little funny out of phase right after the big pulse, but this is fine, less than half rudder and on centerline.
41	3	4	740	1:18:18	[No comments.]
42	5	6	740	1:18:18	Weird. Felt out of control. Looked like right amount of rudder was in initially. Felt like I could recover it until it had reached the end of the runway. I could have given it some right brake.
43	5	6	740	1:18:18	Probably would have called out to first officer, "out of control, help me," probably would have used right brake and reversers.
44	5	6	731	1:18:09	I use a different takeoff technique. Would have started with the left aileron down.
45	5	6	731	1:18:09	I don't like the amount of rudder required but would not have aborted.
46	5	6	735	1:18:13	Going straight down the runway. Would not abort.
47	5	6	736.5	1:18:14.5	Was out of control at that point. Would have full right rudder in, wings level, and tapping right brake for effect.
48	5	6	736.5	1:18:14.5	As soon as I felt I had full right rudder in and still moving left, I would have aborted.
49	5	6	736.5	1:18:14.5	[When would you abort.] I would have aborted at 105 knots, heading 343.

50	6	1	740	1:18:18	Pedals feel different between the seats. The need for right rudder input just calls out. Slow motion is occurring to the left. Why aren't you on the right rudder? [Right seater: Second pedal input feels bigger in the right seat.]
51	6	1	735	1:18:13	At control wheel transition, the nose wheel is at most 10 feet left of the runway centerline. Very slight right bank (1 degree?)
52	9	1	740	1:18:18	Now kick the rudder. Something is missing - right rudder input. With engine failure, it would be the same thing to maintain the centerline, push the feet toward the centerline. First large input is understandable, because below 60 knots the rudder is less effective. As we accelerate, he has to take out the rudder, but gets hit by a gust. He needs more rudder. The amount of rudder during the second large input feels unnatural for that speed. Not supposed to be here.
53	9	1	740	1:18:18	When he takes out the second large rudder input, the airplane moves to the left.
54	9	1	733	1:18:11	Appears to stop on the centerline. [Right seater: It appears that the nose is moving slightly to the left.]
55	9	1	734	1:18:12	[Observer, 6: This time point is close to where the left movement stops.]
56	9	1	735	1:18:13	Removing pedal as wind is pushing tail to the left. This moment the airplane is veering left. The first step would be use the rudder to keep it on the runway. One or two seconds later, if you think you're not going to make it, cut the power.
57	N/A				
58	9	1	736	1:18:14	Heading 347 (3 degrees left from the previous time point ending at 350). [Right seater: Can barely feel the last tiny rudder input.]
59	9	1	740	1:18:18	No comment
60	9	1	740	1:18:18	[Eyes closed] Left seater opened eyes the moment he felt the airplane veering and saw that the airplane was already headed to the left.
61	3	7	740	1:18:18	My impression hasn't changed after visiting the 737 ECAB and feeling its pedals. I still feel like prior to the big excursion I have rudder authority remaining.
62	3	7	Manual pause	Manual pause	[Attempted to pause at gust, but the 6ing of the callout was premature.]
63	3	7	Manual pause	Manual pause	At about 98 knots, I wanted to add additional rudder.
64	3	7	Manual pause	Manual pause	Same comments as trial 63.
65	1	2	740	1:18:18	The big yaw acceleration does not appear to be simultaneous with an abrupt pedal movement.
66	1	2	740	1:18:18	Seems like there is a gust acceleration during the big yaw unrelated to pedal
67	1	2	736	1:18:14	Feels like gusts hitting as rudder coming out the last time, as if the gusts hit him at a bad time.

C.4. Participant General Observations

After all participants completed their simulator observations, a joint debriefing session was held and each participant was given the opportunity to provide general observations about the simulation in a group setting. Participants' observations are reproduced below.

Participant 7

The first abrupt rudder input caught my attention, but it kept the aircraft on the centerline. When the airplane started turning to the left, it felt like there was still controllability left there. My first impression was he should have been able to keep it on the runway. The thought of using tiller never entered my mind because the airplane was just going too fast. Other than that he was doing a fine job controlling it the way he should. As far as the aileron input, his initial left control wheel input seemed appropriate, but I can't imagine grasping the control wheel with my right hand at that point.

Participant 2

First time in the left seat was quite shocking. There was an abrupt shift in heading as the airplane departed the runway to the left. You can look at the data plots and see the rudder input, but when you feel it in the airplane, from the time you begin right rudder to the first hard right rudder input, it seemed like he still had rudder in there until the airplane started veering to the left. However, it felt like there was always some pressure being applied to the right rudder pedal. I wasn't exerting any force with my right leg, however, and when I'm actually flying, I know how much I'm putting in by how much force I'm exerting. You're not feeling how much he's exerting on the pedal in the back-drive. In my opinion, the airplane was veering left while he had right rudder in. At no time did it seem like he had right rudder in there and cause the nose to move right of centerline. Even with full right rudder at 80 knots, I would think that you would be overdoing it, but that wasn't the case. The best he could do was barely keep the nose tracking the way it needed to be tracking. The nose never went too much to the right, and he had to make a full right rudder input to get the right movement at 80 knots.

Participant 6

I seem to have in the window pane a very good reference of where the airplane's nose is compared to the centerline. As soon as I saw that window pane straying to the left, I wanted to put in right rudder to keep that window pane difference the same. My tendency would be to step on the rudder. When we stopped the simulation at the point where the second rudder impulse was made and then released, the right aileron was coming in. He's taking out the right rudder, and he's putting in right aileron. The strategy change occurs there. At that point he's still on the centerline. That's where he reported that he was putting in full right aileron to keep the wings level to keep the airplane from tipping over as he goes off the runway, but he's not close to the edge of the runway yet. I think it's more a primal reaction.

Participant 4

I didn't have any issue believing he was fighting a relatively strong crosswind. Inputs he made early in the roll were what we'd expect. It's obvious he's dealing with gusts because of the two large right rudder inputs he made. The first time through, when we got to the point where he started diverging from the centerline, I really wanted to put right rudder in. It was unnatural for me not to have right rudder in at that point. I can't explain what occurred afterwards. I think there was a distraction of some sort right about a hundred knots, give or take, where his concentration on the outside diverted momentarily. Whether it was a combination of that or taking some of the right rudder out, or a wind gust, when he realized what was happening, I don't know if he had an out at the point in his mind. He was controlling the aircraft and then suddenly headed to the left side of the runway.

Participant 8

The initial roll and inputs were all exactly what I would expect. First leveling the yoke and then putting in the wind correction. The first full stab of right rudder was appropriate because he was drifting left of centerline. He achieved a heading differential bringing him back, so it was natural to take a little of that out. It's unfortunate that he took out a little too much. It's an indication of a real strong crosswind that the airplane started tracking left again pretty quickly. Then, he puts full or nearly full rudder in again. When you look at it in a macro sense, his second large rudder input did not elicit a correct or expected airplane response. It could very well be a gust that did not allow that expected reaction to occur. At that point, I have to believe that he took his attention away from looking outside or got distracted by something because he relaxed the right rudder pressure after the second large right rudder input. I don't what the distraction would have been, possibly checking the airspeed, engine instruments, or whatever, but I feel he wasn't looking outside because you would have expected another rudder stab. Instead there is a relaxation and the heading drifts left. Inappropriate control inputs follow. I did not see another stab of right rudder, and I saw aileron going in the wrong direction. The accident captain later reported that he went for the tiller. I don't know if you would call that a panic reaction. If he was distracted and looked up to see the airplane sliding sideways, he might have been able to reject the takeoff, but unfortunately he did not decide to stop at that point. I know of past previous accidents and incidents where people panic and go for the tiller at both low and high speeds during the takeoff roll. They are still trying to save the takeoff. I think the accident captain tried to save the takeoff. I don't know how long he might have been distracted, but it would only have taken a second before he would have been unable to prevent the airplane from departing the runway. From a human factors point of view, the night visual scene seemed to reduce perceptions of yaw, and after the relaxation of the second large right rudder input, I think that a pilot could think he had full right rudder in the whole time. That might explain why he might take his eyes off the runway or otherwise become distracted in some way.

Participant 5

The progression for me watching it was very normal. He did a good job of tracking it down the runway until he didn't, and that was a very, very fast change. As far as keeping it on the centerline, his speed came up appropriately, it all looked good until it didn't.

Participant 1

He appeared to be tracking really accurately in the beginning. He did not have a lot of heading change, but he had really big rudder excursions. This could reduce the association between flight control input and aircraft response. Also the high average amount of rudder required could lead to confusion about the absolute rudder position at any particular point in time. I felt one or two rapid onset yaws or lateral accelerations after the second large right rudder input had been fully relaxed and they seemed to come at the worst possible time, exacerbating the effect of relaxing the rudder. It felt like he needed a little more rudder the second time, and I'm not sure whey he didn't use more. It didn't feel like there was a rapid succession of oscillations about a central point. There were very small heading changes near the centerline until the big heading excursion. I noticed during the first rudder input it was pretty surprising that he needed a full deflection at 70+ knots to get it to come back to centerline. The amount of rudder required at that point would definitely get his attention. The use of full rudder and hitting the stop with only a little right heading change might have shaken his confidence at that point.

Participant 9

Was not surprised he kicked in full rudder at the very beginning of takeoff roll (between 45 and 60 knots). The rudder is not fully effective in the B-737 until an airspeed of about 60 knots. The tiller should not be used beyond 20 or 30 knots maximum. There is a gap between 30 and 60 knots. During the speeds in between, all you can do is give it all the rudder you have. The captain may have been surprised at how much rudder he needed and started a chain of events in his mind thinking that the crosswind was much worse than he expected. I think it is a combination of too much rudder and wind gusts. With all the rudder pedal inputs and the airplane remaining on the centerline, it tells me there was over controlling. I believe there was a disconnect between what he's doing and airplane's response. Probably a distraction around 100 knots when he took the rudder out. We did a run where we closed our eyes and I opened them when I felt the airplane was sliding sideways. When I opened my eyes, the airplane was already headed 3 or 4 degrees off centerline. His impression may have been that something happened to the airplane. If he was distracted, he would have had only seconds to reconstruct his mental model of the situation and he may have run out of time.

Participant 3

The scenario involving a distraction, raised by other participants, makes sense. During the simulated tiller grab, where I transitioned to tiller as the control wheel moved to the right, I was very shocked at how early in the sequence he might have transitioned to tiller, but a distraction could explain why he stopped tracking the centerline (around 98-100 knots or earlier). If he brought his attention inside the cockpit and then looked up and saw the airplane moving to the left, the unexpected picture could have mentally rattled him a little bit. My initial impression was that there was plenty of rudder authority left at 98-100 knots.