NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, DC

January 27, 1998

Rudder Jam Simulation Study

By Dennis Crider

A. ACCIDENT DCA-94-MA-076

Location: Aliquippa, Pennsylvania
Date: September 8, 1994
Time: 1904 Eastern Daylight Time
Aircraft: Boeing 737-300, N513AU

B. GROUP IDENTIFICATION

This study was conducted under the Aircraft Performance Group. However, group participation was limited to report review.

C. SUMMARY

On September 8, 1994 at 1904 Eastern Daylight Time, USAir Flight 427, a Boeing 737-3B7, N513AU, crashed while maneuvering to land at Pittsburgh International Airport, Pittsburgh, Pennsylvania. The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title 14, code of Federal Regulation (CFR), Part 121, on a regularly scheduled flight from Chicago O'Hare International Airport, Chicago, Illinois, to Pittsburgh. The airplane was destroyed by impact forces and fire near Aliquippa, Pennsylvania. All 132 persons on board the airplane were fatally injured.

D. DETAILS OF INVESTIGATION

Overview

In August 1997, tests were conducted by the systems group on the USAir427 PCU with the secondary slide jammed in various positions. Simulations were run using rudder rates and available hinge moments from these tests to determine whether, in light of this data, a secondary slide jam was consistent with Flight Data Recorder (FDR) data.

Procedure

The simulation was conducted using the Safety Board's 737-300 simulation. The simulation was modified to apply a user input multiplication factor to the rudder hinge moment limit table lookup results. This was used to model the degradation in available rudder hinge moment measured for a jammed secondary slide. Rudder traces were input directly from a file (and overridden by the simulation when they reached the hinge moment limit).

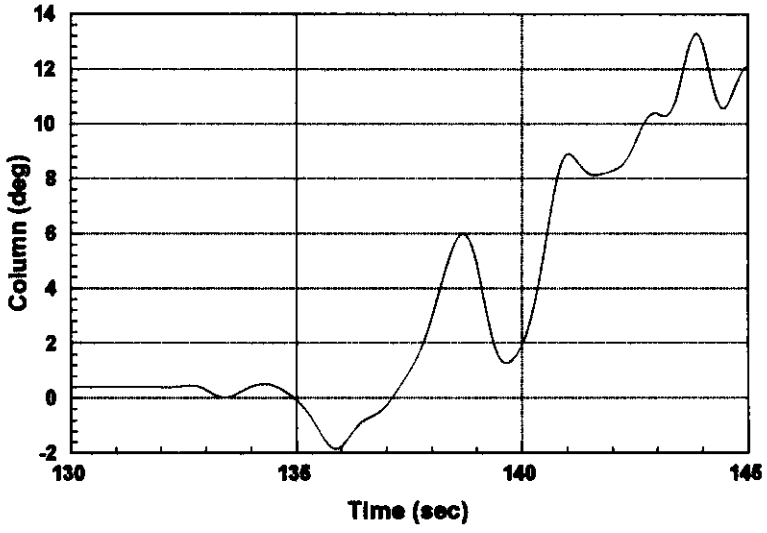
The simulation was started at time = 130 seconds. At this point flight 427 was in a turn at a changing flight state. Accordingly, the simulation was trimmed to the following dynamic condition for all cases presented in this study.

Airspeed = 189.835 KCAS
Altitude = 5817.5 ft
Heading = 106.75 deg
Pitch Angle = 7.22 deg
Bank Angle = -13.89 deg
Control column = 0.4 deg
Pitch Rate = 0.4 deg/sec
Yaw Rate = -1.17 deg/sec
Roll Rate = 0.45 deg/sec

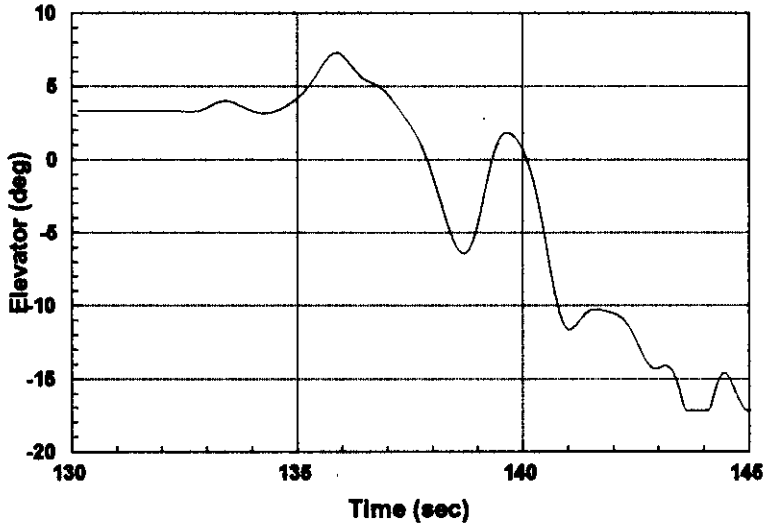
Except for the angular rates, these conditions came from the FDR. The angular rates were iterated from their initial estimated values to match the initial portion of the flight path.

The pitch control column was available from the FDR. The equivalent stabilizer was derived from NTSB kinematics analysis and was also used in the simulation runs in Attachment 9 of the Kinematics Validation Study. It represents excess pitching moment not accounted for by the column. The pitch control parameters are common to all simulations in this document and are given on the following three plots.

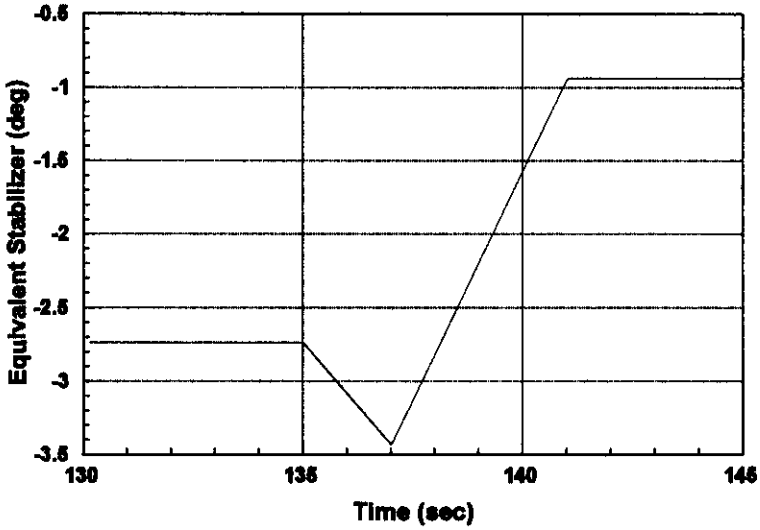
USAir427
FDR Column



USAir427
Elevator from FDR Column

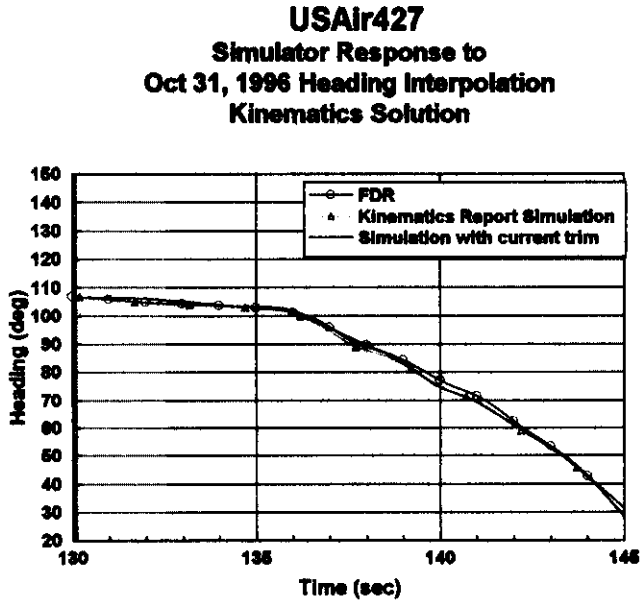


USAir427
NTSB Kinematics Result



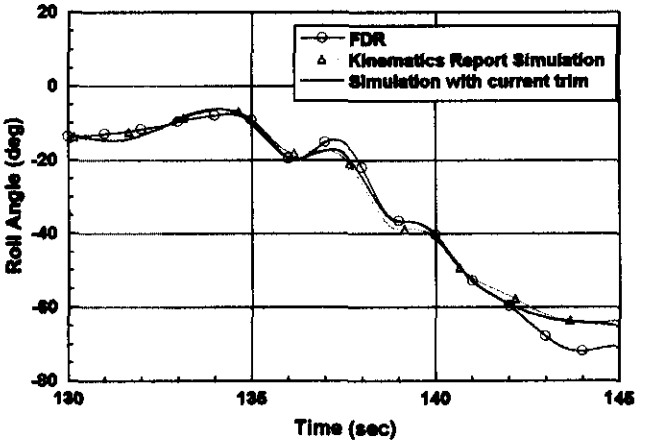
Baseline Cases

To provide a figure of merit and to allow convenient cases for comparison with cases from Attachment 9 of the Kinematics Validation Study with the same trim condition[1], two cases from the Kinematics Validation Study were re-run. Thus the simulation was run using control inputs from the October 31st 1996 Boeing kinematics solution and the Run 82 kinematics solution. Simulator response to the October 31st kinematics solution is presented on the following pages. Both the data originally plotted in the Kinematics Validation Study and responses starting from the current trim are plotted for comparison.

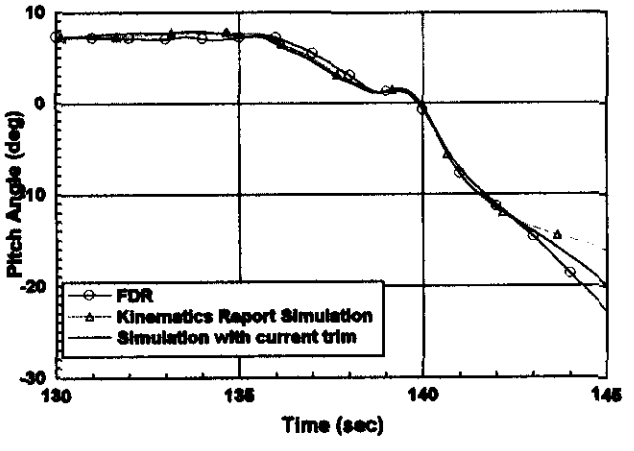


[1] The angular rates for the trims in the Kinematics Validation Study were not preserved.

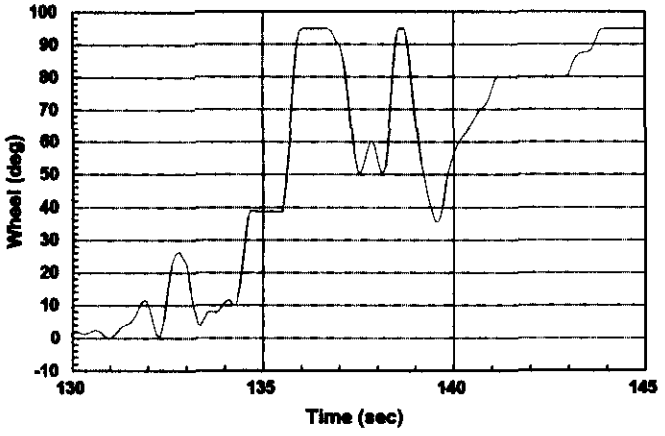
USAir427
Simulator Response to
Oct 31, 1996 Heading Interpolation
Kinematics Solution



USAir427
Simulator Response to
Oct 31, 1996 Heading Interpolation
Kinematics Solution



USAir427
Oct 31 1996 Kinematics Result



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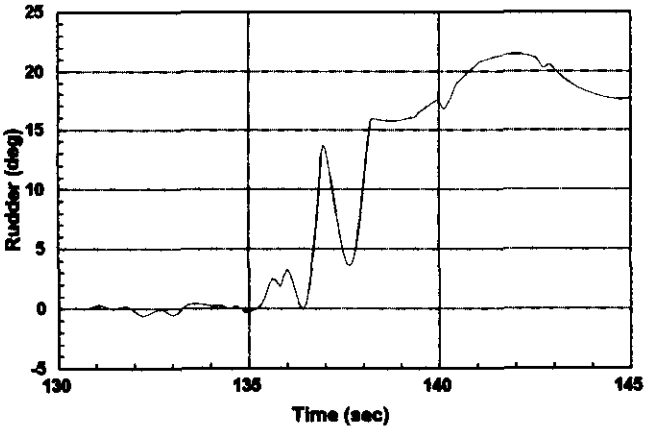
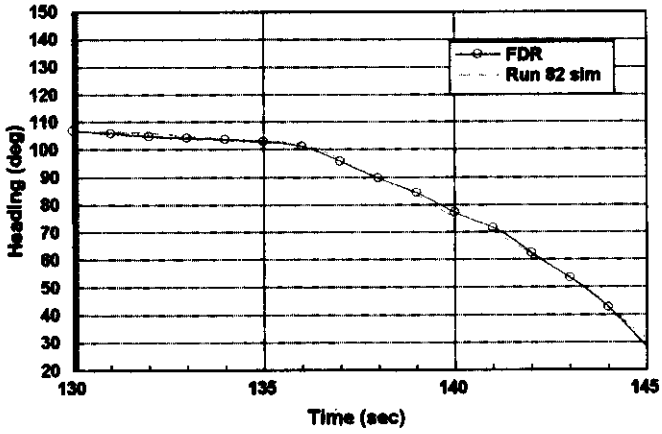
Oct 31 1996 Kinematics Result

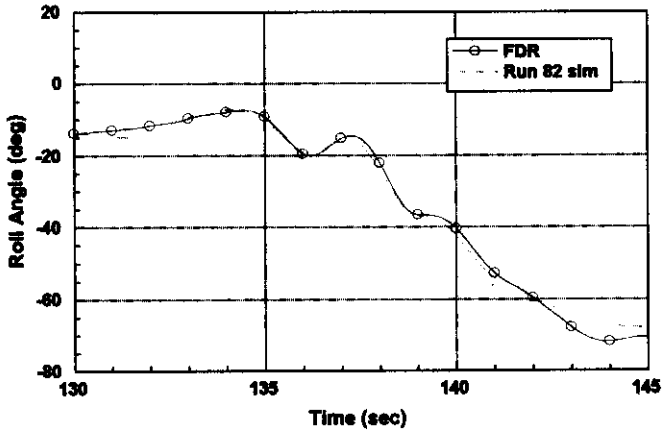


Simulator response to the Run 82 kinematics solution is presented on the following pages.

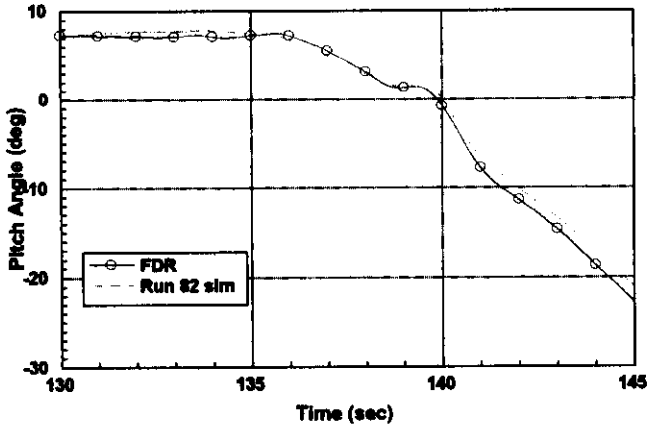
USAir427
Simulator Response to
Run 82 Heading Interpolation
Kinematics Solution



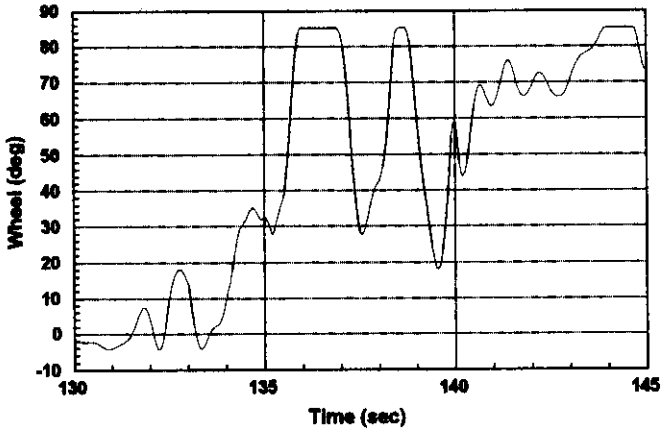
USAir427
Simulator Response to
Run 82 Heading Interpolation
Kinematics Solution



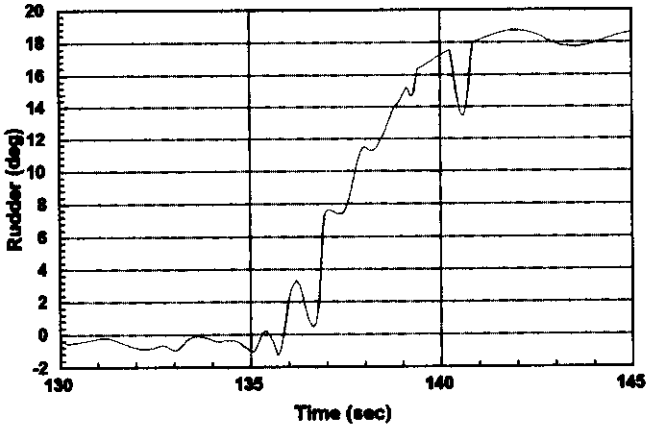
USAir427
Simulator Response to
Run 82 Heading Interpolation
Kinematics Solution



USAir427
Run 82 Kinematics Result



USAir427
Run 82 Kinematics Result



<u>Jam Simulation</u>

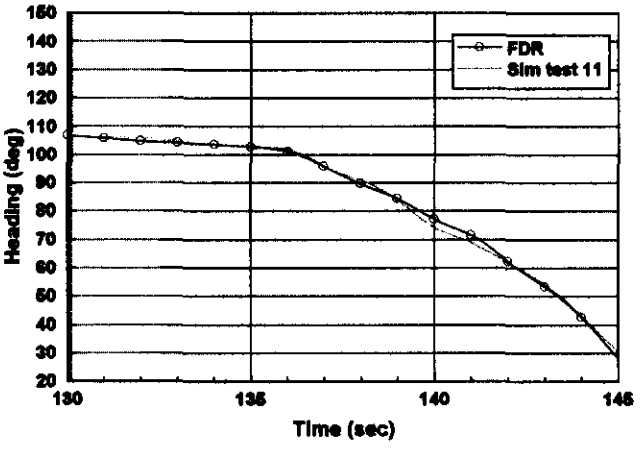
The August 1997 systems group test of a jammed secondary slide provided rate and hinge moment data that was used to define rudder traces for the simulation. The kinematics results from Run 82 were used as a baseline for the input controls. The rudder trace would depart this baseline at time = 135.7 seconds and move in a positive direction at the rate from the test to the 3 degree yaw damper limit. The rudder would then hold at 3 degrees for a time before resuming the test rudder rate to +23 degrees (the simulation would override the command file rudder input when the rudder hinge moment limit was reached). The time the rudder held at 3 degrees was varied iteratively until either a match was found as good as the baseline cases, or a determination was made that a match is not possible for that jam displacement.

Hinge moment limits and rudder rates for the Jams were derived from data on page 4 of Systems Group Chairman's Factual Report Addendum Rudder PCU Testing (October 10, 1997). This data is summarized below for test in which both a rate and load were obtained.

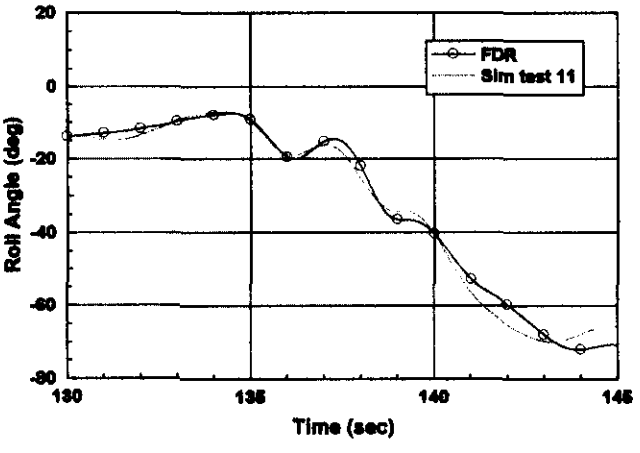
Secondary Jam Displacement	Test	Rudder Rate	Hinge Moment Limit Ratio
71%	11	26.6 deg/sec	0.93
50%	9	17.8 deg/sec	0.88
22%	6	9.5 deg/sec	0.76
12%	5	4.0 deg/sec	0.50

The simulation results for a 71% displacement secondary slide jam are given on the following pages.

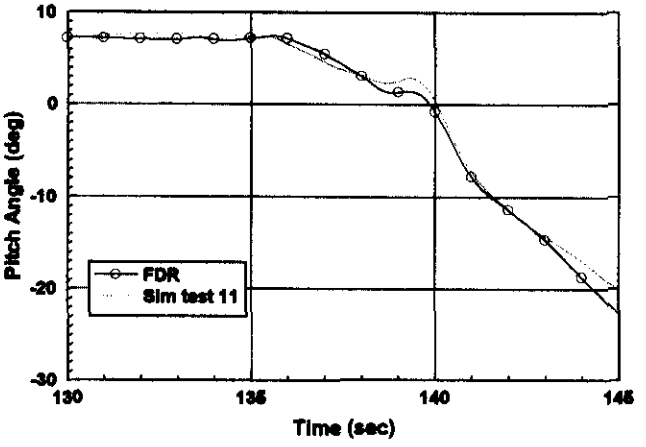
USAir427
Simulator Response to
Test 11 Rudder Jam
(71% Jam)



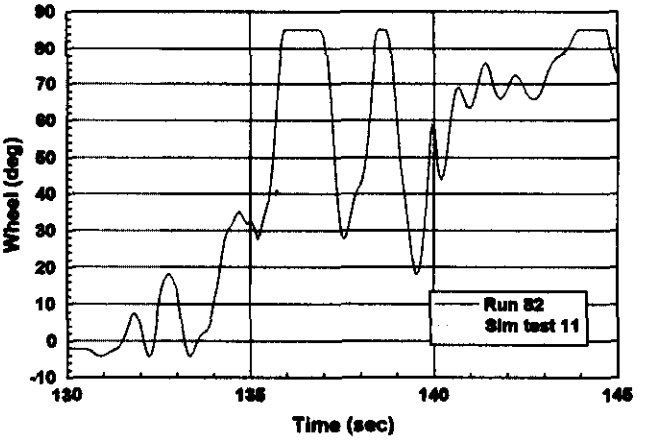
USAir427
Simulator Response to
Test 11 Rudder Jam
(71% Jam)



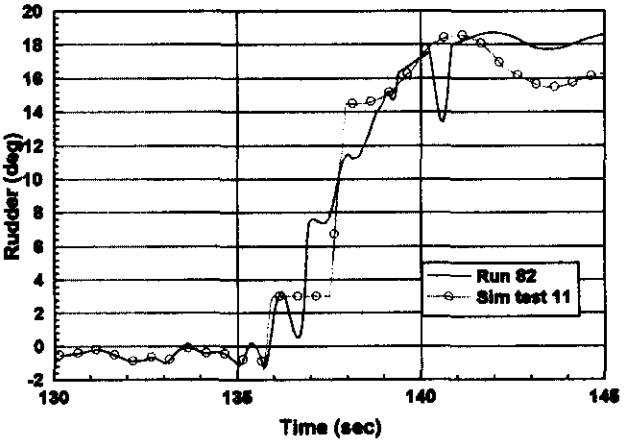
USAir427
Simulator Response to
Test 11 Rudder Jam
(71% Jam)



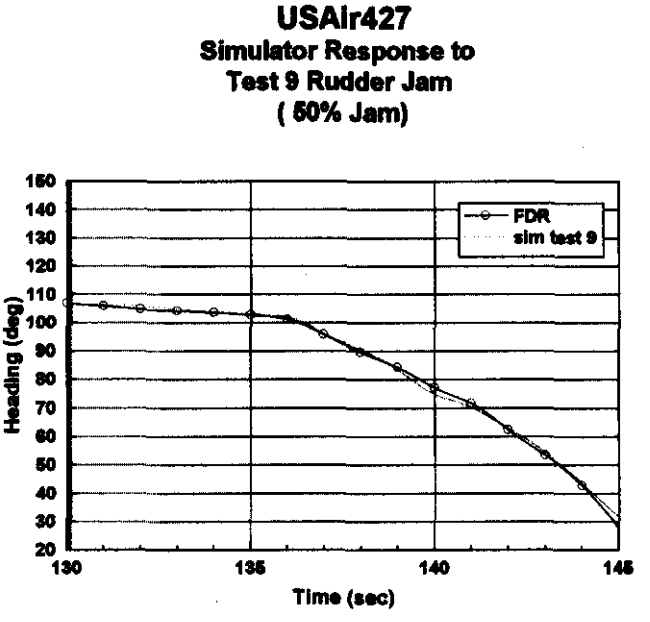
USAir427
Simulator Response to
Test 11 Rudder Jam
(71% Jam)



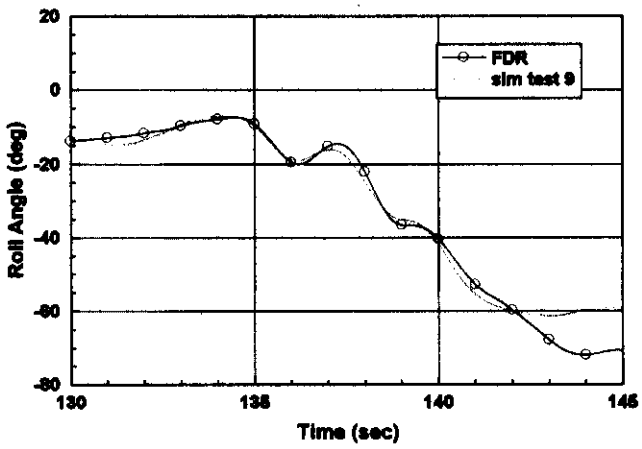
USAir427
Simulator Response to
Test 11 Rudder Jam
(71% Jam)



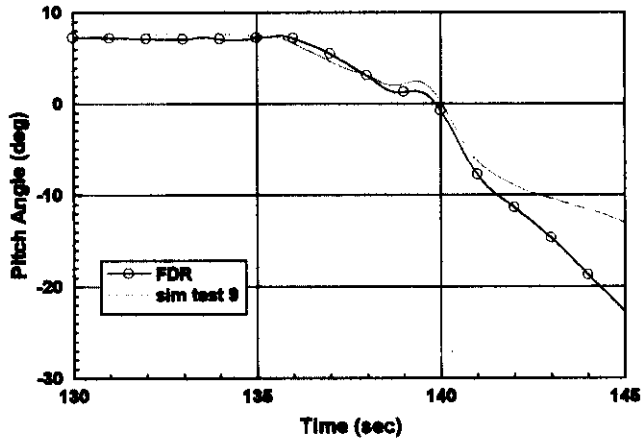
The simulation results for a 50% displacement secondary slide jam are given on the following pages.



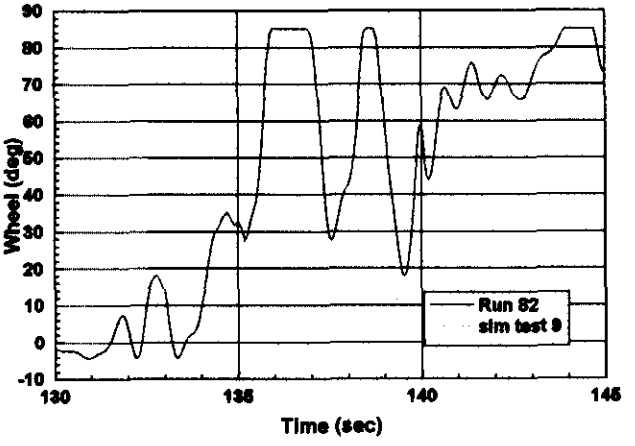
USAir427
Simulator Response to
Test 9 Rudder Jam
(50% Jam)



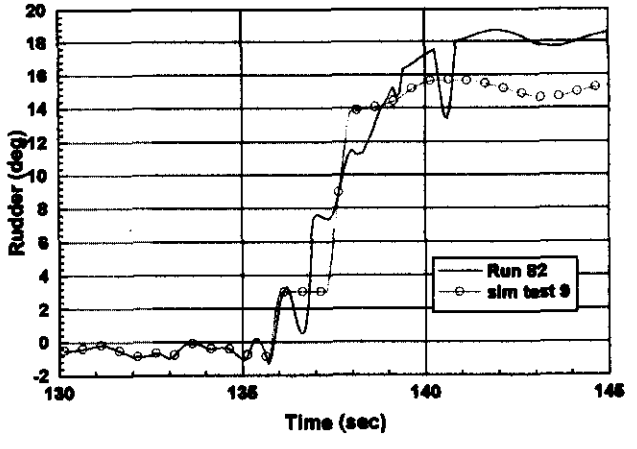
USAir427
Simulator Response to
Test 9 Rudder Jam
(50% Jam)



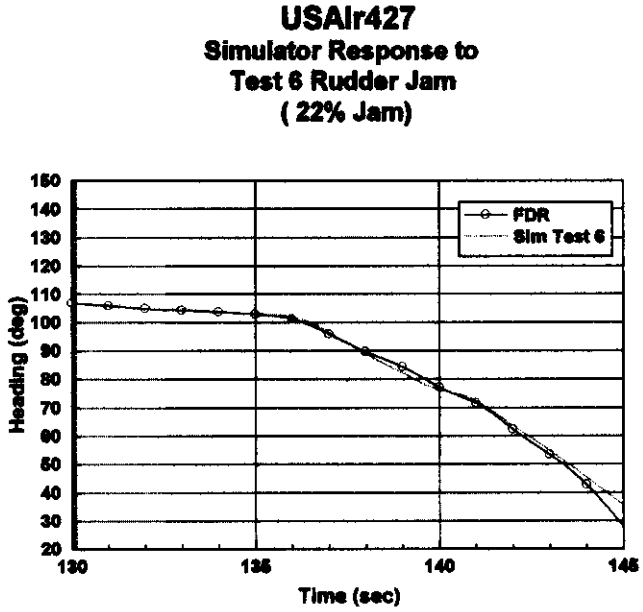
USAir427
Simulator Response to
Test 9 Rudder Jam
(50% Jam)



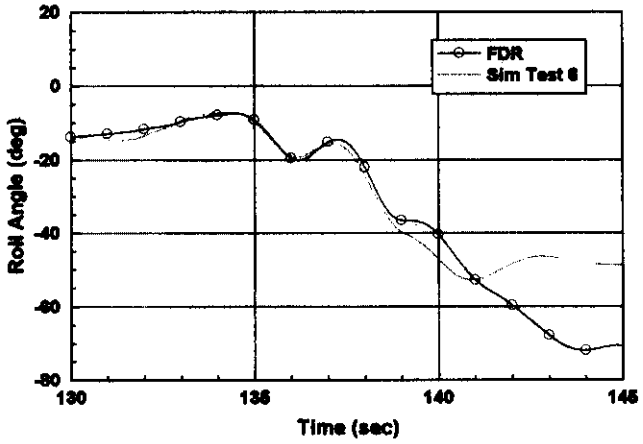
USAir427
Simulator Response to
Test 9 Rudder Jam
(50% Jam)



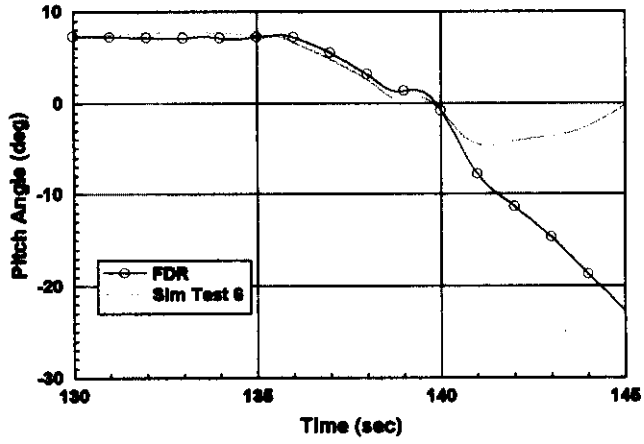
The simulation results for a 22% displacement secondary slide jam are given on the following pages.



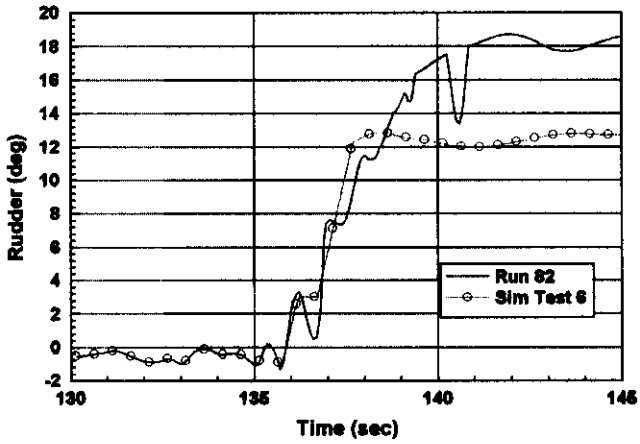
USAir427
Simulator Response to
Test 6 Rudder Jam
(22% Jam)



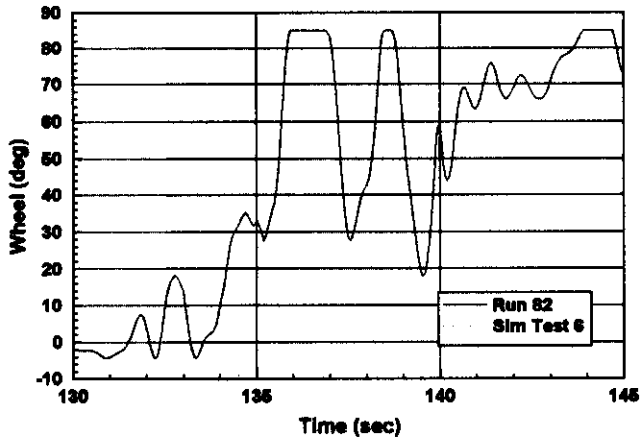
USAir427
Simulator Response to
Test 6 Rudder Jam
(22% Jam)



USAir427
Simulator Response to
Test 6 Rudder Jam
(22% Jam)



USAir427
Simulator Response to
Test 6 Rudder Jam
(22% Jam)



Rudder time histories were developed for the 71% and 50% secondary slide displacement jams that produced simulations that were consistent with the FDR. It was not possible to produce results consistent with the FDR with a 22% secondary slide displacement jam. Since even less rudder deflection is possible with a 12% secondary slide displacement jam, it was concluded that the 12% secondary slide displacement jam would not be consistent with the FDR. Thus the 12% secondary slide displacement jam was not simulated.

[redacted]

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