**Boeing Commercial Airplane Group**
P.O. Box 3707
Seattle, WA 98124-2207

May 29, 1997
B-B600-16147-ASI

Mr. Greg Phillips
National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594-2000

BOEING

Subject: Test and Analysis, Minimum Clearance Control Valve -US Airways 737-300 Accident, N513AU, near Pittsburgh, Pennsylvania, 8 September 1994

Reference: A) Meeting with Panel, April 3, 1997
B) Fax Howes/Phillips, *Interim Report,* February 25, 1997
C) Boeing Letter B-B600-16611-ASI, Robinson to Loeb, Item 2, May 12, 1997

Dear Mr. Phillips:

As you requested in the reference (a) meeting, we have enclosed a copy of test and analysis of the thermal jam potential of a 737 rudder power control unit (RPCU) with a minimum clearance control valve. In this meeting, we understood that this report would be used to address any issues that the NTSB or the Systems Group Panel have regarding the effects of a potential thermal jam for the 737 RPCU control valve.

This report is intended to clarify the information provided in reference (b), and to complete the action requested in reference (c). A copy of this report has been provided to the FAA.

If you have any questions, please contact me.

Very truly yours,

[redacted]

for John W. Purvis
Director, Air Safety Investigation
Org. B-B600, M/S 67-PR
[redacted]

Enclosure: Boeing's *Test and Analysis of 737 Rudder Power Control Unit (PCU) Valve Thermal Jam Potential*

cc: Tom Haueter, NTSB, AS-10
Bernie Loeb, NTSB, AS-1

# Test And Analysis Of 737 Rudder Power Control Unit (PCU) Valve Thermal Jam Potential

**Reference** (a) Letter To NTSB B-B600-15972-ASI, 737-1/2/3/4//500 Rudder Power Control Unit (PCU) Thermal Test Report, dated 2/12/97


## Summary

This report covers testing that was conducted at the Boeing Integrated Airplane System Lab (IASL) between February 22 and March 17, 1997, to determine the susceptibility of 737 rudder PCU control valves to thermal jamming. The testing was conducted as a certification test and was witnessed by the FAA.

The testing demonstrated that a minimum clearance valve did not seize under worst case thermal overheat conditions and with the highest level of rudder activity that would be expected in flight. The testing also demonstrated that the valve would not seize for a hot day condition.

The valve did seize for thermal shock conditions that were well beyond any reasonable temperature conditions that could be anticipated in flight. For example, when hot fluid was introduced directly into the PCU after it had been cold soaked while depressurized. The minimum clearance valve seized when the PCU fluid inlet temperature was 140 ° F above the valve housing temperature. Under the same condition, the Flight 427 valve seized at a temperature difference of 175 ° F. This was expected since the minimum clearance valve had smaller diametric clearances for both primary and secondary slides than did the Flight 427 valve.

## Background

The Reference (a) thermal testing of the Flight 427 rudder PCU established that this particular control valve could not be jammed under any thermal conditions that could reasonably be encountered in flight. The present testing was conducted to address the question of whether or not PCU control valves installed in other airplanes could be susceptible to thermal jams.

To provide an answer, a minimum diametric clearance valve was manufactured such that it would just pass the valve maximum friction requirements. A test was then set up, using this valve, to mimic the worst case thermal conditions that an airplane could reasonably encounter.

## Test Plan

The primary purpose of the 737 rudder PCU thermal lab test was to determine if a rudder PCU with a minimum diametric clearance valve can seize under the most extreme temperature conditions that would be anticipated after a hydraulic overheat failure.

Two conditions are required to cause a valve seizure due to thermal effects. The first is a severe hydraulic system overheat failure condition. The second condition is that there must be very high rudder and elevator hydraulic flow to quickly draw the hot fluid from the overheated hydraulic reservoir to the cold soaked rudder PCU. Preliminary experimentation showed that this second condition could be satisfied when the rudder was displaced from zero to full left, then full right and back twice within 9 seconds.

The test setup replicated the thermal environmental conditions of the airplane hydraulic system and PCU. This was accomplished by using hydraulic tubing that replicated the airplane tubing from the wheel well, where the system relief valve is located, to the PCU. Tubing that represented airplane tubing in unpressurized areas, as well as the PCU, was contained in a cold chamber. All other tubing was kept at room temperature. The Reference (a) flight testing had determined the ambient temperatures in the 48 section (unpressurized section aft of the pressure bulkhead) and in the PCU cavity after a high altitude two hour cold soak. This temperature (-23° F), or colder, was maintained in the cold box throughout the thermal shock temperature testing.

The hydraulic fluid temperatures during the thermal shock testing were designed to replicate a pump compensator failure causing the engine driven pump to put out excessive flow. This failure raises the system pressure until the relief valve opens to throttle the excess flow to the reservoir, thereby heating the hydraulic fluid. To achieve this condition in the lab test, the A hydraulic system was set to 3700 psi supply pressure and the hydraulic reservoir was rapidly heated to approximately 200° F. The B hydraulic system reservoir temperature was kept at approximate 65 ° F during the test.

The level of rudder activity is important to any thermal shock analysis. Higher rudder activity results in higher flow to the rudder PCU, which in turn causes greater temperature gradients within the valve. To determine maximum levels of rudder activity, time histories of rudder deflection were examined from flight test data for crosswind landings and wake vortex encounters. Enclosure A provides data used for certifying crosswind landing on the various model 737s and as well as data for wake vortex encounters. The accumulated rudder travels versus time for the cases with the highest rudder activity are plotted in Figure 1.

The yaw damper was used to simulate rudder activity levels in terms of total rudder travel over a given time period for various cross wind landing and go around conditions. The accumulated rudder travels versus time are shown in Figure 1. To simulate this rudder activity in the Lab test, the yaw damper was cycled by using a +/- 3 degree square wave command at frequencies of 0.5, 1.0, and 1.5 hertz. The time histories of equivalent rudder travels at these frequencies are also plotted in Figure 1 for comparison with the flight test data. Figure 1 shows that the 1.5 hertz yaw damper cycling resulted in greater rudder activity than any of the crosswind landings. The square wave +/- 3 degree yaw damper command was used in the test because the square wave command can stroke the secondary valve slide (slide is stroked about 50 % of the maximum travel). During the test, the minimum clearance valve was also manually cycled to full displacement because of the possibility that the secondary slide was more likely to seize at this condition.

To simulate the thermal effect of elevator activity, a leakage flow of 2500 cc/min was set for the A hydraulic system. This represents the in-service specification limit for autopilot servo neutral leakage of 1600 cc/min and adds 500 cc/min for the elevator PCU. To take account the higher supply pressure effect (3700 psi versus 3000 psi), the above flow was increased from 2100 cc/min to 2500 cc/min.

The test simulated a hydraulic system overheat due to an EDP failure for the following flight conditions:

- the worst flight case conditions which include
  - ~ high altitude cruise, followed by a high level of yaw damper activity

- crosswind landing, high level rudder activity occurs when the overheated hydraulic fluid reaches the rudder PCU.
- crosswind landing, high level rudder activity occurs after the overheat hydraulic failure occurs at cruise

- hot day operation (i. e.; with 160 degrees hydraulic fluid in both A and B systems)

- extreme thermal shock condition, which was conducted in the Reference (a) thermal shock test condition G, to compare the jam susceptibility between the Flight 427 valve and the minimum clearance valve.

**Test Setup**

~ Test rig configuration

The test setup schematic is shown in Enclosure B. The PCU and the coiled hydraulic tubing simulate the airplane tubing from the wheel well to the rudder PCU. The wheel well tubing and the tubing from the aft pressure bulkhead to the PCU, as well as the PCU itself, were contained in a cold chamber. The remaining tubing was outside the cold chamber.

The bench hydraulic fluid had been obtained from the Reference (a) thermal shock test. During the testing, the fluid particulate level was in the range of NAS 1638 Class 11. The fluid sample analysis report is in Enclosure C.

~ Test Unit

The main control valve used for the testing was specially made by Parker to achieve a minimum diametric clearance while still passing the servo valve assembly and PCU acceptance test requirements. The valve diametric clearances and other related measurements are listed in the following table:

| | outside diameter (inch) | diametric clearance (inch) | straightness (inch) | roundness (inch) |
|---|---|---|---|---|
| Primary Slide | 0.25 | 0.00011 | 0.00003 | 0.00001 |
| Secondary Slide | 0.75 | 0.00007 | 0.00001 | 0.00001 |

Note, roundness tolerance controls the dimension regarding how round the slide is by measuring the maximum deviation in the radius of the slide. Straightness tolerance controls the dimension regarding how straight the slide is by measuring the maximum radial deviation along the longitudinal axis of the slide.

**Test Procedure**

Pretest condition:

For each of the following conditions the PCU was cold soaked to -23 degrees F or colder for 2 hours or until all temperatures had stabilized. The A system pump reservoir was heated to 200 degrees F as rapidly as possible, just prior to the start of each test condition, unless otherwise specified for conditions. The B hydraulic system reservoir temperature was kept at approximate 65 ° F during the test. The A system pressure was set to 3700 psi and B system pressure was set to 3000 psi. To simulate the thermal effect of elevator activity, a leakage flow of 2500 cc/min was used for the A hydraulic system. During the cold soak, the yaw damper was cycled at +/- 1 degree at 0.3 hertz.

Condition 1. Overheat at cruise:

The cold soak yaw damper cycling was sustained until the PCU inlet temperature just started to rise. At this point the yaw damper was commanded with a + or - 3 deg., .3 hertz square wave to conservatively simulate flying through turbulence. The square wave was sustained for 5 minutes.

Condition 2. Landing after overheat:

a. the cold soak yaw damper cycling was sustained until the PCU inlet temperature started to rise, then the yaw damper input was increased to + or - 3 degrees at 0.5 hz. After 15 seconds of +/- 3 degrees cycling, a manual force pulse of + or - about 20 lb was applied such that the secondary valve slide was bottomed. After approximately 30 seconds, a manual force pulse was again applied. This ended the test condition.

b. Repeated condition (a) except increased square wave frequency to 1.0 Hz.

c. Repeated condition (a) except increased square wave frequency to 1.5 Hz.

d. Repeated condition (c) except that the +/- 3 degrees yaw damper cycling was not started until the PCU inlet fluid temperature had stabilized.

Condition 3. Hot day simulation.

The PCU was hot soaked and the temperature was stabilized at 161 degrees F. Both A and B hydraulic systems were heated to 172 degrees. The simulated airplane hydraulic tubing was bypassed so that the hot fluid was provided directly to the PCU hydraulic inlets. The PCU was cycled by using square wave command of +/- 1 degrees at .3 during hot soak, then switched to +/- 1 degrees at 3 hz for 38 seconds, then changed to +/- 3 degrees at 1hz for 56 seconds, then was manually commanded at the maximum rate for several cycles.

Condition 4. Jam susceptibility comparison with Flight 427 valve

The PCU was cold soaked at -40 degrees while depressurized. The A hydraulic system was then heated to 170 degrees and the hot fluid was introduced directly into PCU. The PCU was manually cycled at maximum rate through full stroke until the valve seized.

**Results**

The test results for the worst flight case conditions after a hydraulic overheat failure and hot day conditions are summarized in Table 1. The time history plots of the temperatures are included in Figures 2 and 3. Figure 2 shows the PCU inlet fluid temperature versus time for the various test conditions in Table 1. Figure 3 shows the time history of the temperature difference between the inlet fluid and the outside surface of the valve housing for the same conditions. The figure shows that the higher frequency cycling resulted in a relatively higher rate of change in delta temperature. The control valve operated normally for each of the test conditions (conditions 1 through 3), that was designed to simulate in air hydraulic overheat cases.

Note that condition 2.d shows a higher delta temperature (147° F) than the other conditions without valve seizure. For this case the inlet fluid temperature was allowed to stabilize before the rapid cycling started. This stabilization time allowed the secondary slide as well as the matching valve body sleeve to warm up. This resulted in a less severe thermal gradient between the slide and the sleeve than that in test condition 4 where the valve seized at a delta temperature of 145 ° F.

For the hot day simulation (condition 3), the PCU inlet temperature was 173 degrees F and the outside surface of the valve housing temperature was 175 degrees. No valve seizure or anomaly was found for this condition.

Condition 4 was to compare the jam susceptibility between the minimum clearance valve and the Flight 427 valve. Figure 4 shows the delta temperature time history comparison of essentially identical thermal shock test conditions. The data shows the minimum clearance valve seized at a delta T of 145 degrees and the Flight 427 valve seized at 175 degrees. Note that the measure diametric clearance for the Flight 427 valve secondary slide is approximately 0.00013 inches compared to 0.00007 inches for the minimum clearance valve.

Table 1 737 Rudder PCU With a Minimum Clearance Valve Thermal Test Data For Potential Flight Conditions

| Lab Test Case Number | Lab Test Condition | Y/D Command (degrees ) | Maximum Delta T (degrees F) ** | Valve Seizure Status |
|---|---|---|---|---|
| 1 | Cruise | +/- 1 @ 1 hz | 115 | No |
| 2. a | Landing after overheat | +/- 3 @ .5 hz | 100 | No |
| 2. b | same | +/- 3 @ 1 hz | 110 | No |
| 2. c | same | +/- 3 @ 1.5 hz | 120 | No |
| 2. d | Landing after overheat with time for temp. to stabilize | +/- 3 @ 1.5 hz | 147 | No |
| 3 | Hot Day Simulation | +/- 3 @ 1hz | -2 | No |

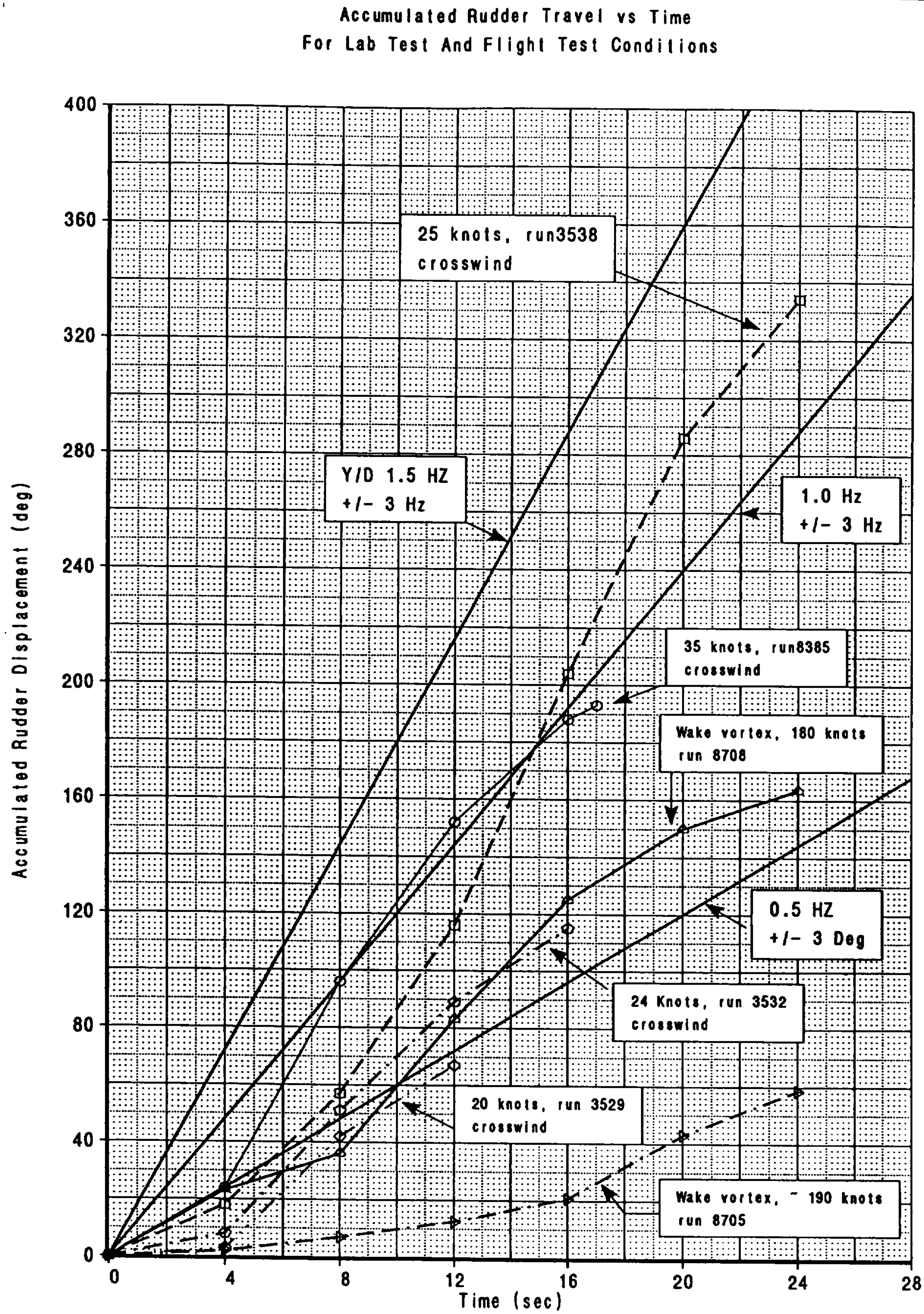
** Note, delta T is the temperature difference between the PCU A system hydraulic inlet and the outside surface of the valve housing

Analysis of the data indicates that all the control valve seizures in the thermal shock tests occurred between the secondary slide and valve body sleeve, i. e. the primary slide did not seize at all. This is due to the fact that the secondary slide diameter is 3 times bigger than the primary slide (0.75 inches versus 0.25 inches). Therefore, the secondary slide diameter will expand 3 times more than the primary slide if the same temperature difference between the slide and sleeve is assumed for both slides. Also the diametric clearance for the secondary slide/housing is smaller than the diametric clearance between the primary slide and secondary slide (i. e., 0.00007 inches versus 0.00011 inches).

**Conclusion**

The data and analysis presented in this report demonstrate that a 737 rudder PCU with a minimum diametric control valve will not seize in any flight scenario due to overheating of the hydraulic fluid, even with fluid particulate level in the range of NAS 1638 Class 11. The test results also showed the minimum clearance valve seized at a lower temperature gradient than the Flight 427 valve in an extreme thermal shock condition. This verifies that the minimum clearance valve is more susceptible to a thermal jam than the Flight 427 valve. However, since the minimum clearance valve did not seize in any flight scenario, it is concluded that a thermally induced seizure of a 737 rudder PCU is not a reasonably postulated failure mode.

Enclosure A: 737 Rudder Crosswind Landing And Wake Vortex Flight Test Data
Enclosure B: Test Setup Schematic for 737 Rudder PCU Thermal Shock Test
Enclosure C: Lab Hydraulic Fluid Sample Analysis Report




[A]: /disk/d4/737_thermal/rud.esb

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|---|---|---|---|---|---|---|
| CALC | David Wang | 21May97 | REVISED | DATE | Fig. 1 Rudder Accumulated Travel vs Time For Lab Test And Flight Test Conditions | 737 Classic |
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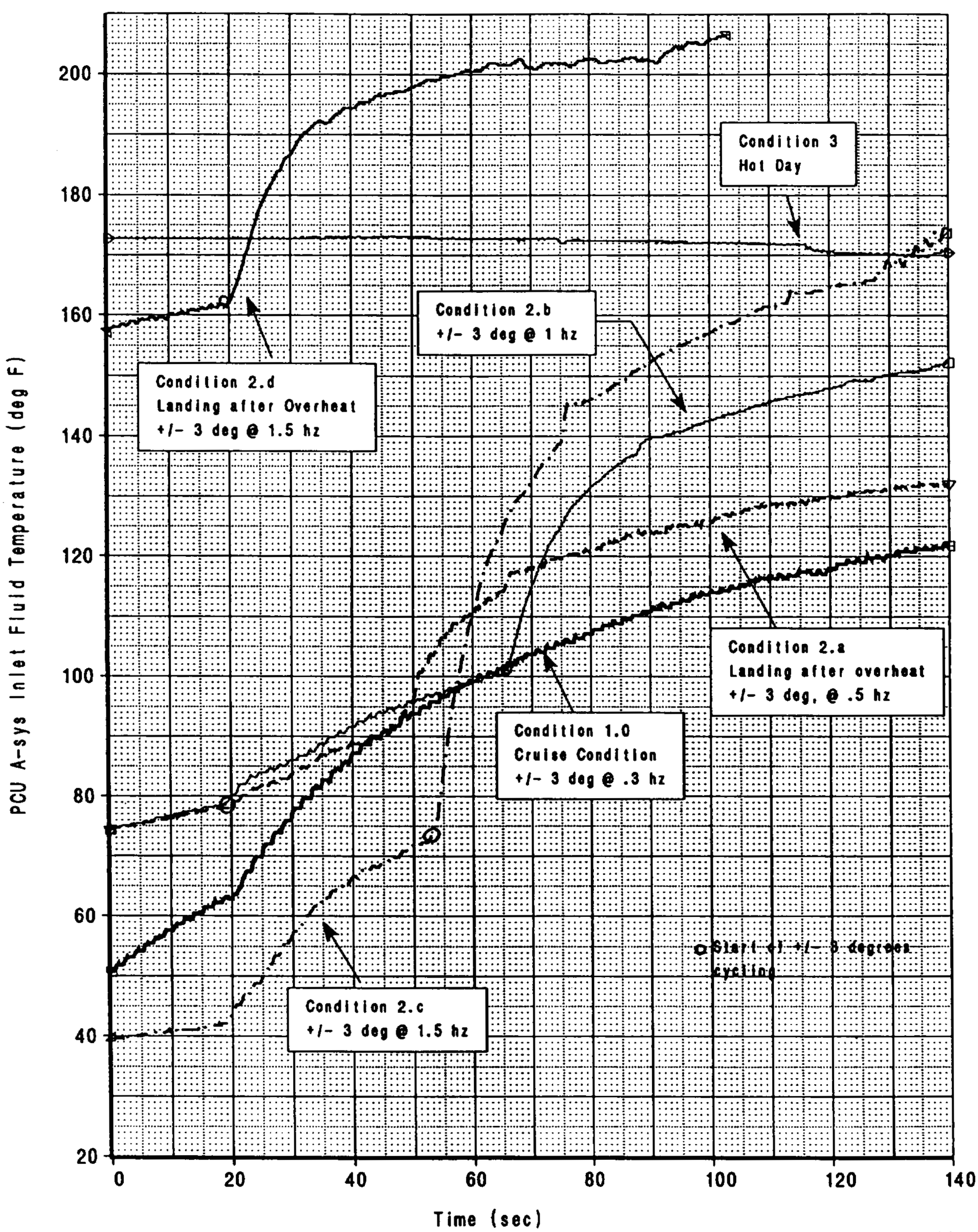
| Plot | David Wang | | | | | |

PCU Hydraulic A System Inlet Temperatures VS Time For
Lab Conditions 1, 2.a, 2.b, 2.c, and 2.d

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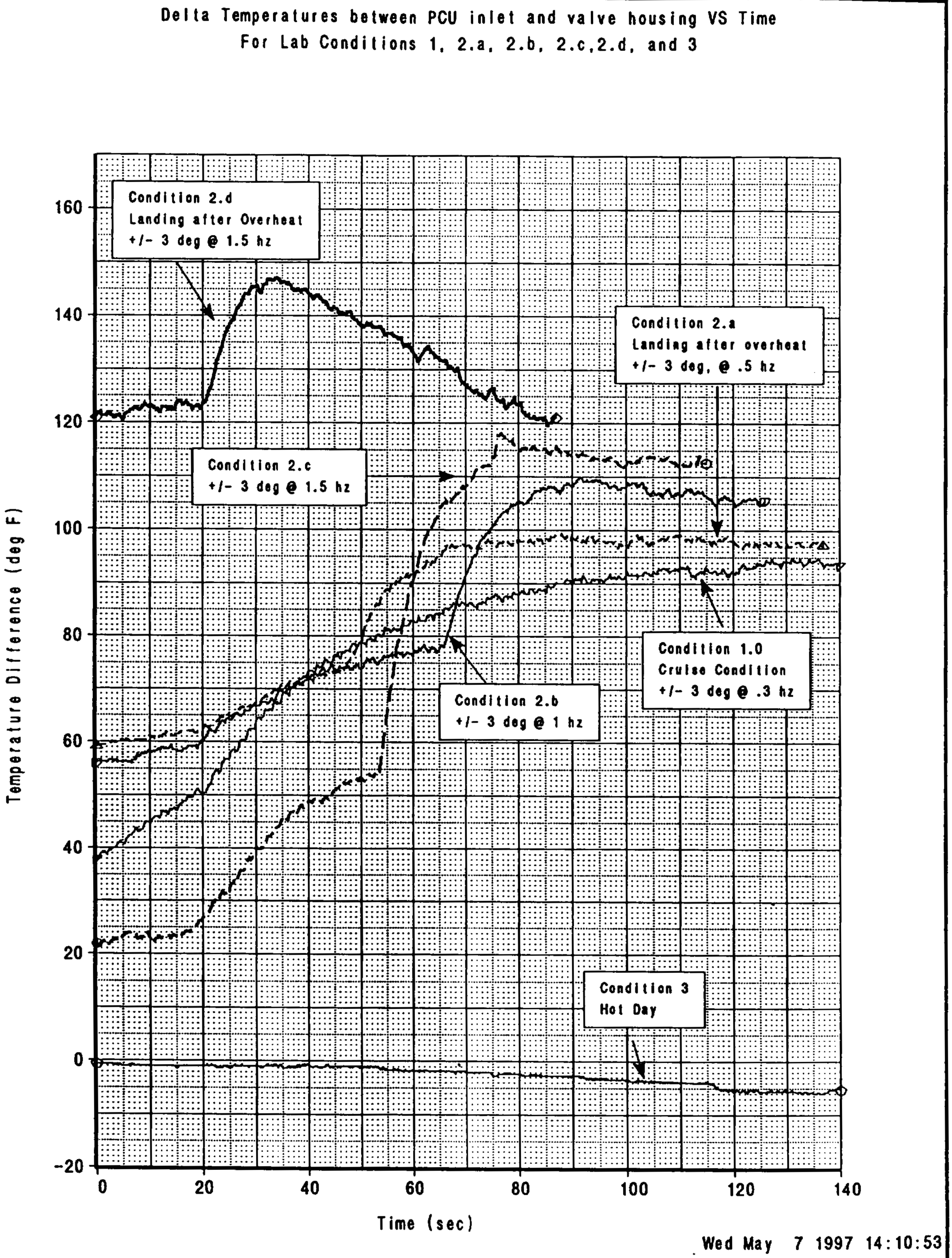


| CALC | David Wang | 7May97 | REVISED | DATE | Delta temperatures vs Time For Lab Conditions 1, 2,and 4 | 737 Classic |
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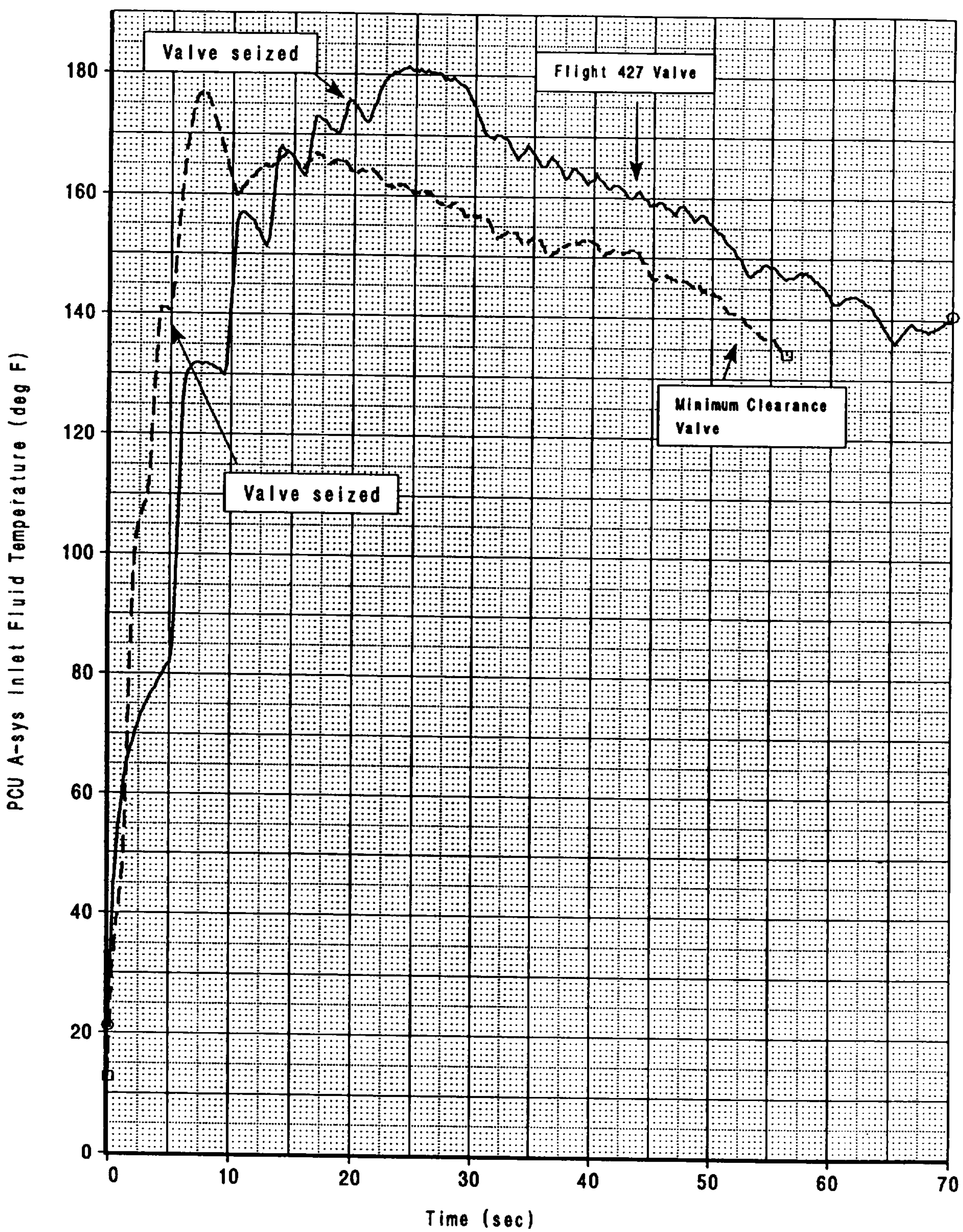
| Plot | David Wang | | | | | |

Temperature difference between the PCU inlet and Valve housing VS Time
For a minimum clearance valve and 427 valve
under the extreme thermal shock condition

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| APPD. | | | | | BOEING | PAGE |
| Plot | D. Wang | 294-7952 | | | | |

# ENCLOSURE A-1: FLIGHT TEST CERTIFICATION RESULTS FOR 737-300 CROSSWIND LANDINGS

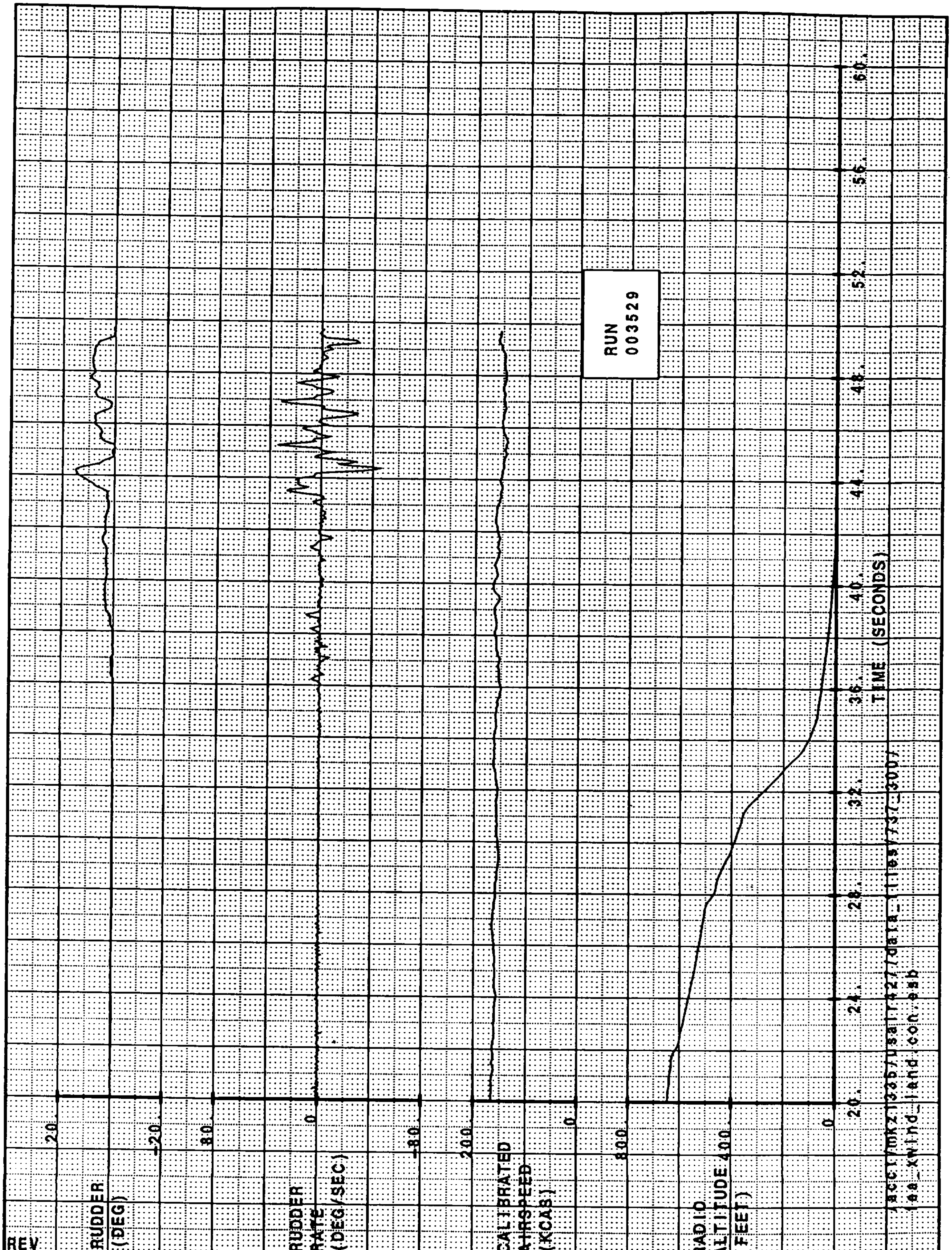


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FIGURE E1.1: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 20 KTS

737-300

RUN 3529

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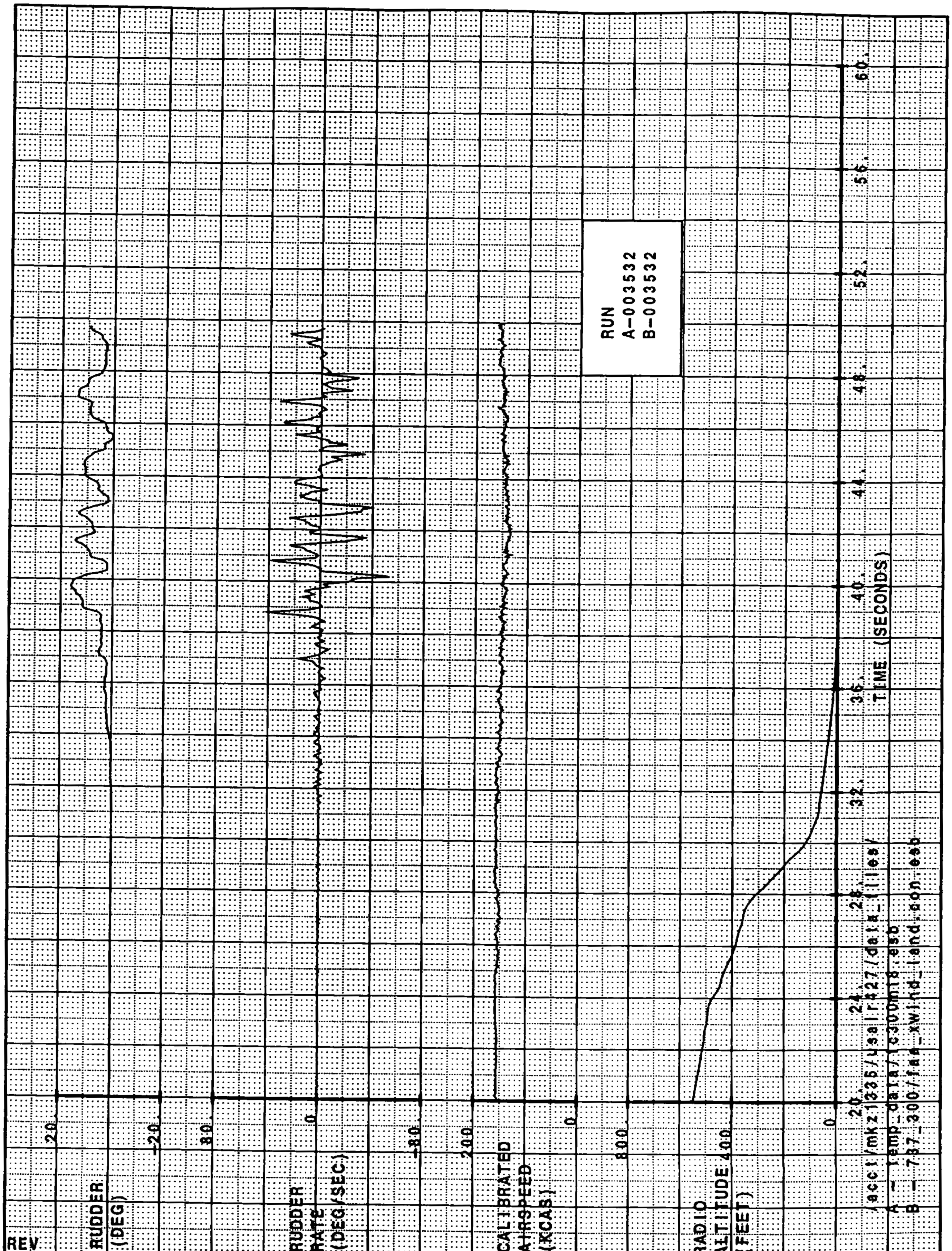


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**FIGURE E1.2: CROSSWIND LANDING FLIGHT TEST RESULTS CROSSWIND COMPONENT = 24 KTS**

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737-300

RUN 3532

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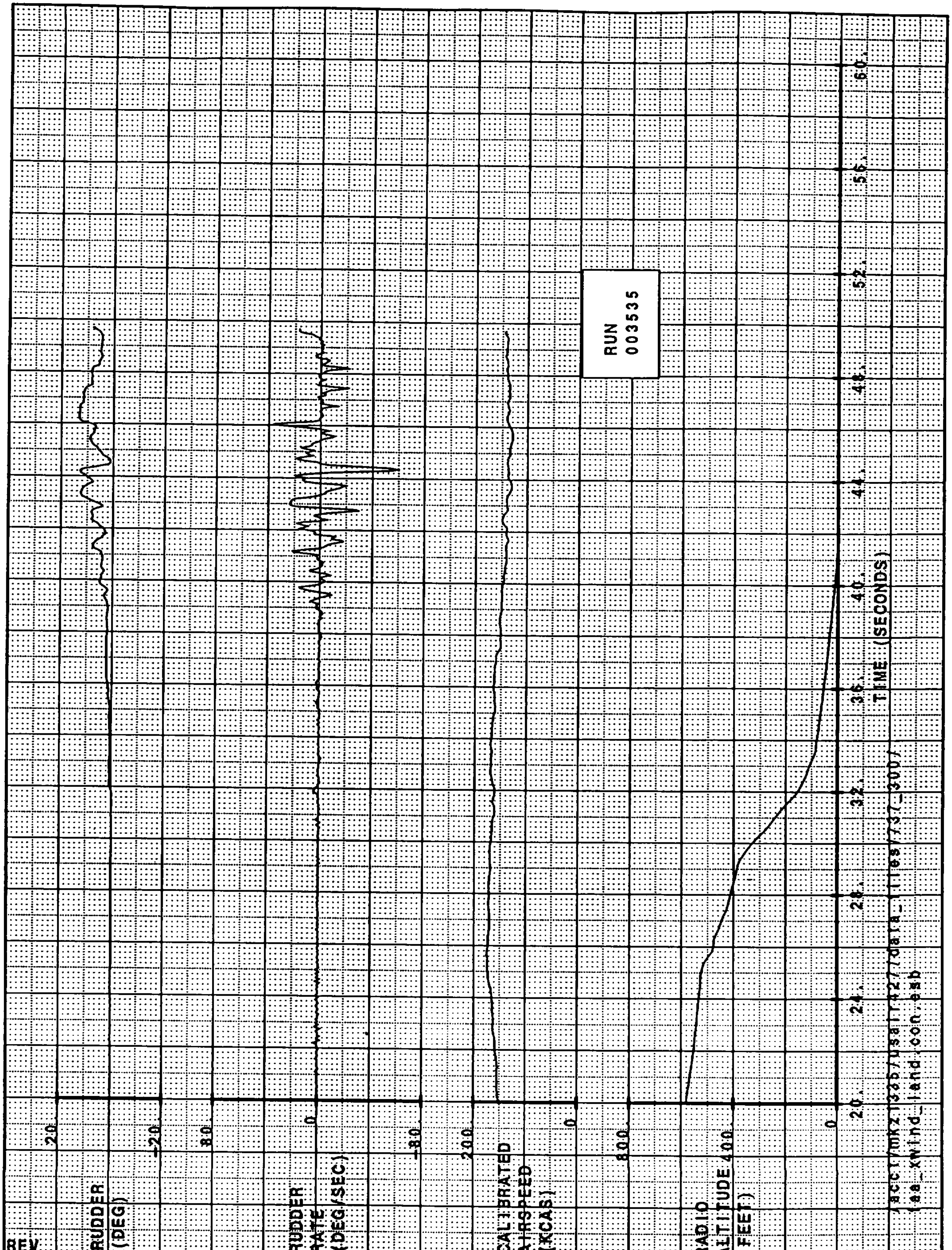


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FIGURE E1.3: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 24.5 KTS

737-300

RUN 3535

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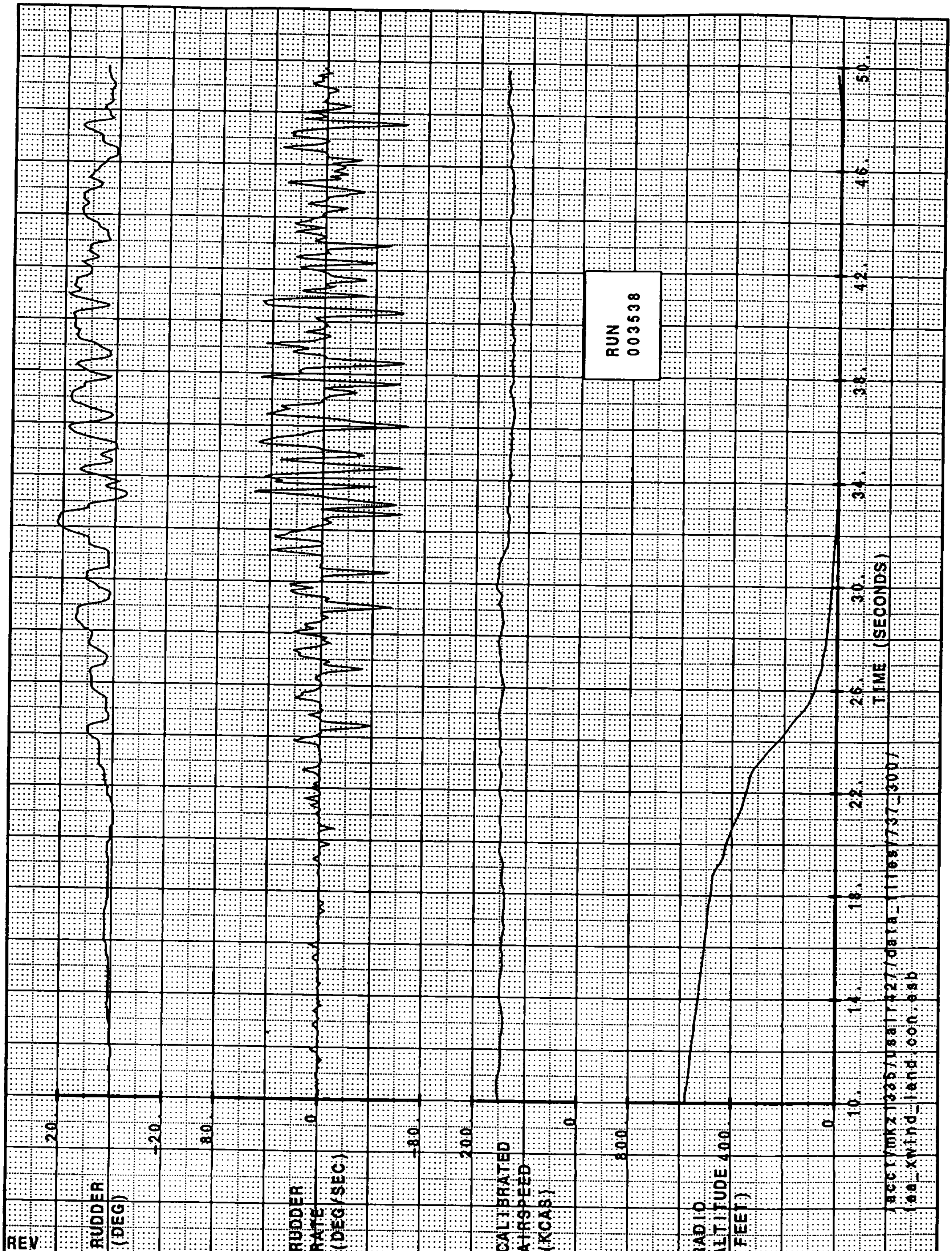


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FIGURE E1.4: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 25 KTS

737-300

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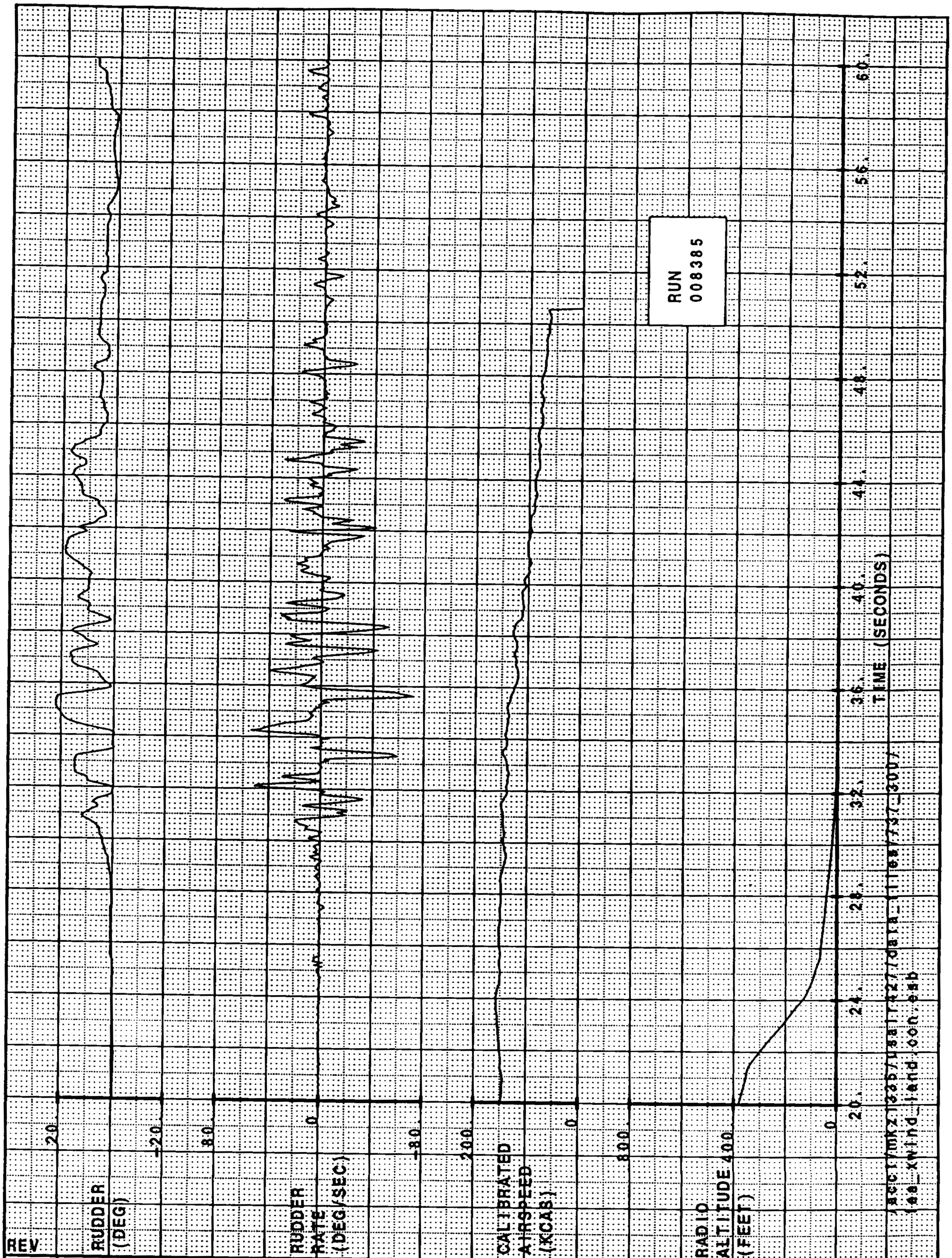


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FIGURE E1.5: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 35 KTS

737-300

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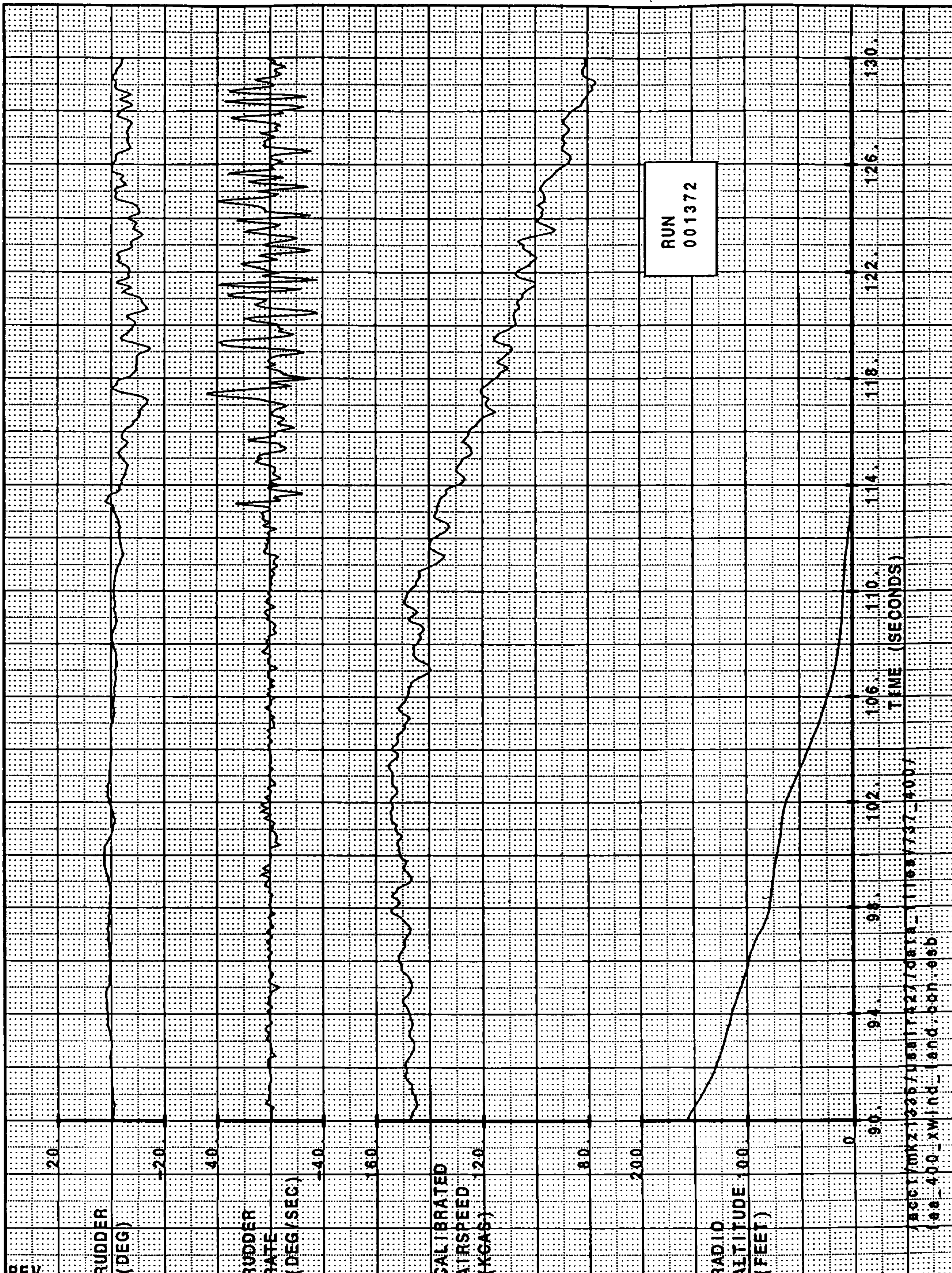
A-2

# ENCLOSURE : FLIGHT TEST RESULTS FOR 737-400 CROSSWIND LANDINGS

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| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E2.1: CROSSWIND LANDING<br>FLIGHT TEST RESULTS<br>CROSSWIND COMPONENT = 9 KTS | 737-400 |
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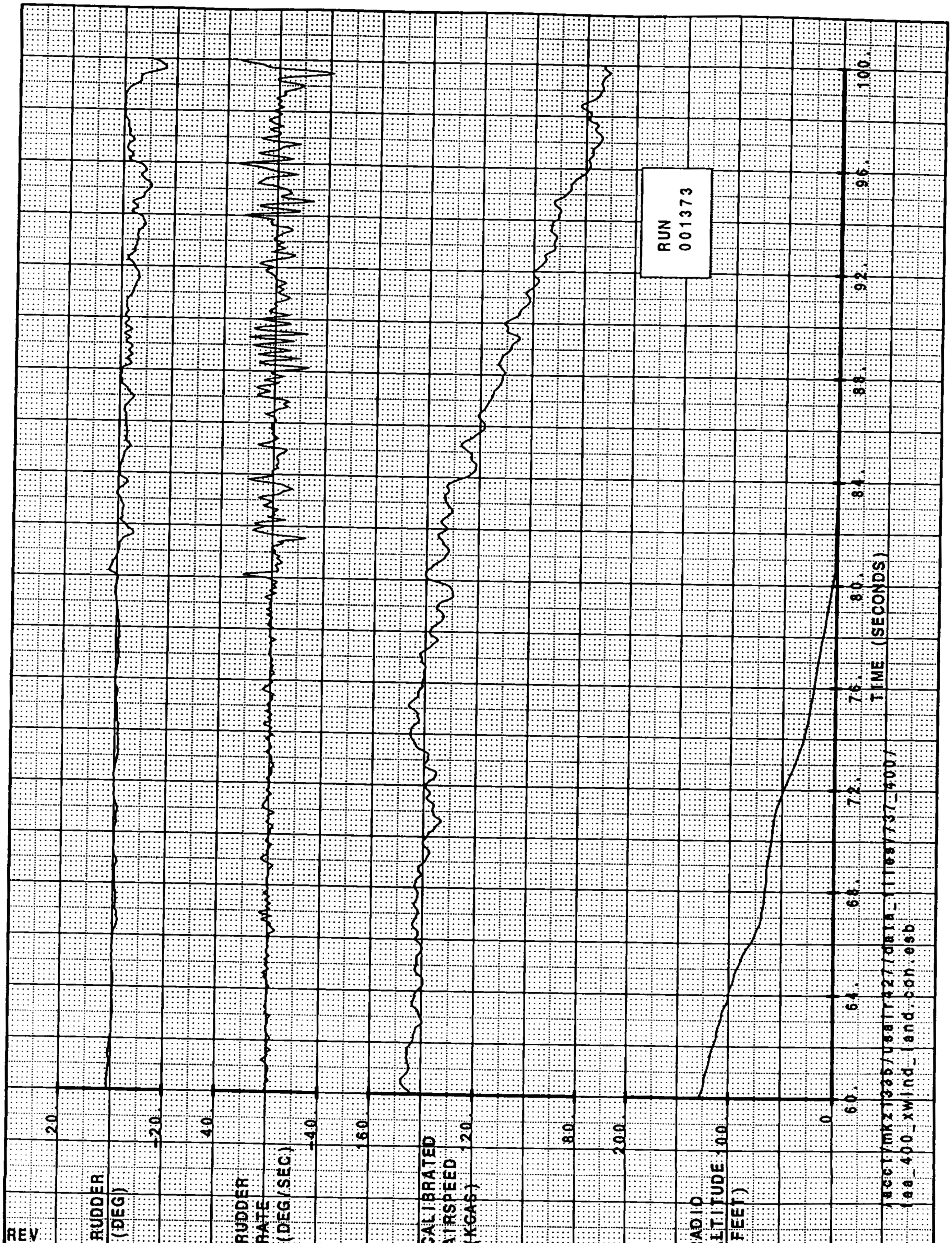


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FIGURE E2.2: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 5 KTS

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737-400

RUN 1373

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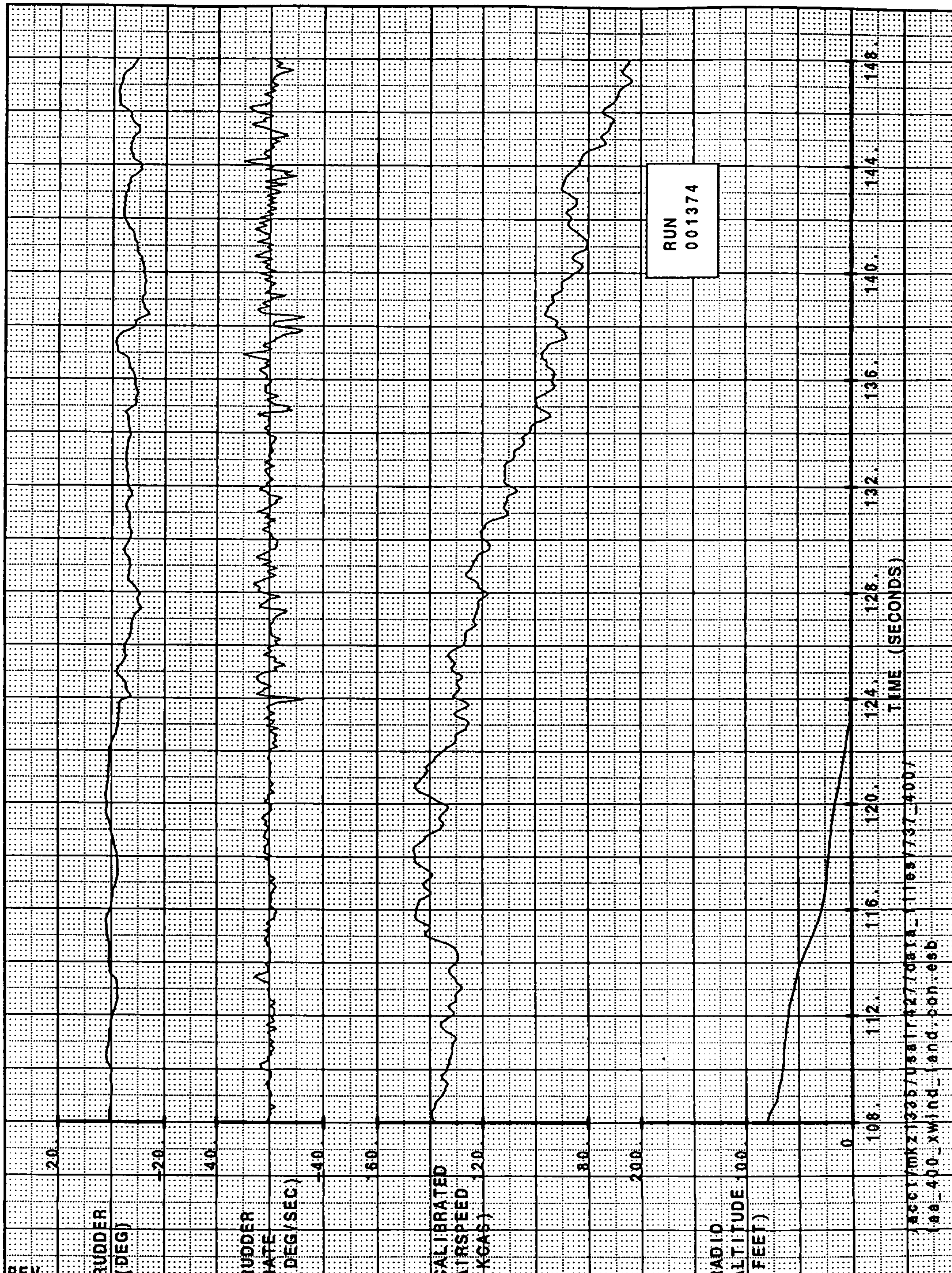


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| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E2.3: CROSSWIND LANDING<br>FLIGHT TEST RESULTS<br>CROSSWIND COMPONENT = 13 KTS | 737-400 |
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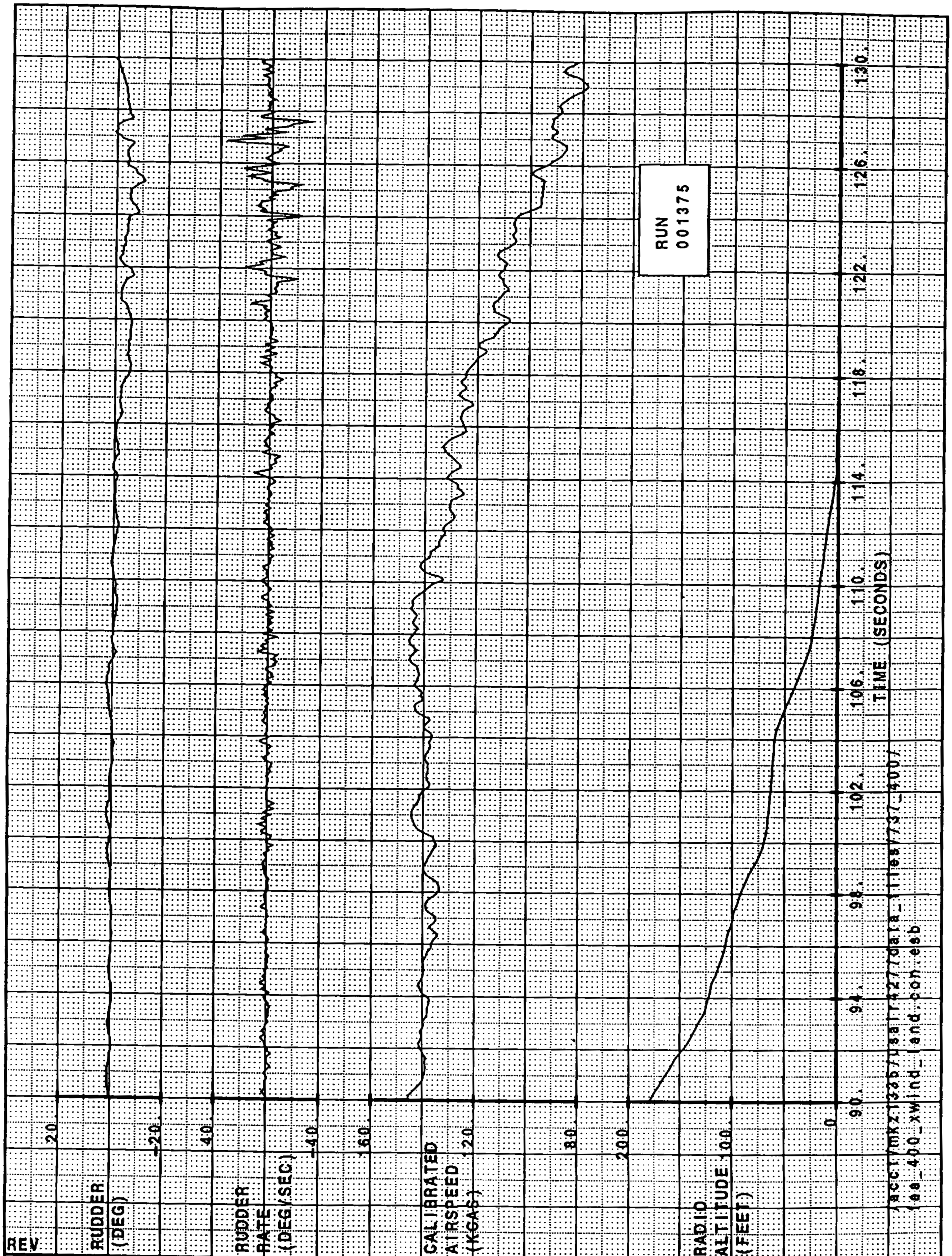


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FIGURE E2.4: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 9 KTS

737-400

RUN 1375

THE BOEING COMPANY

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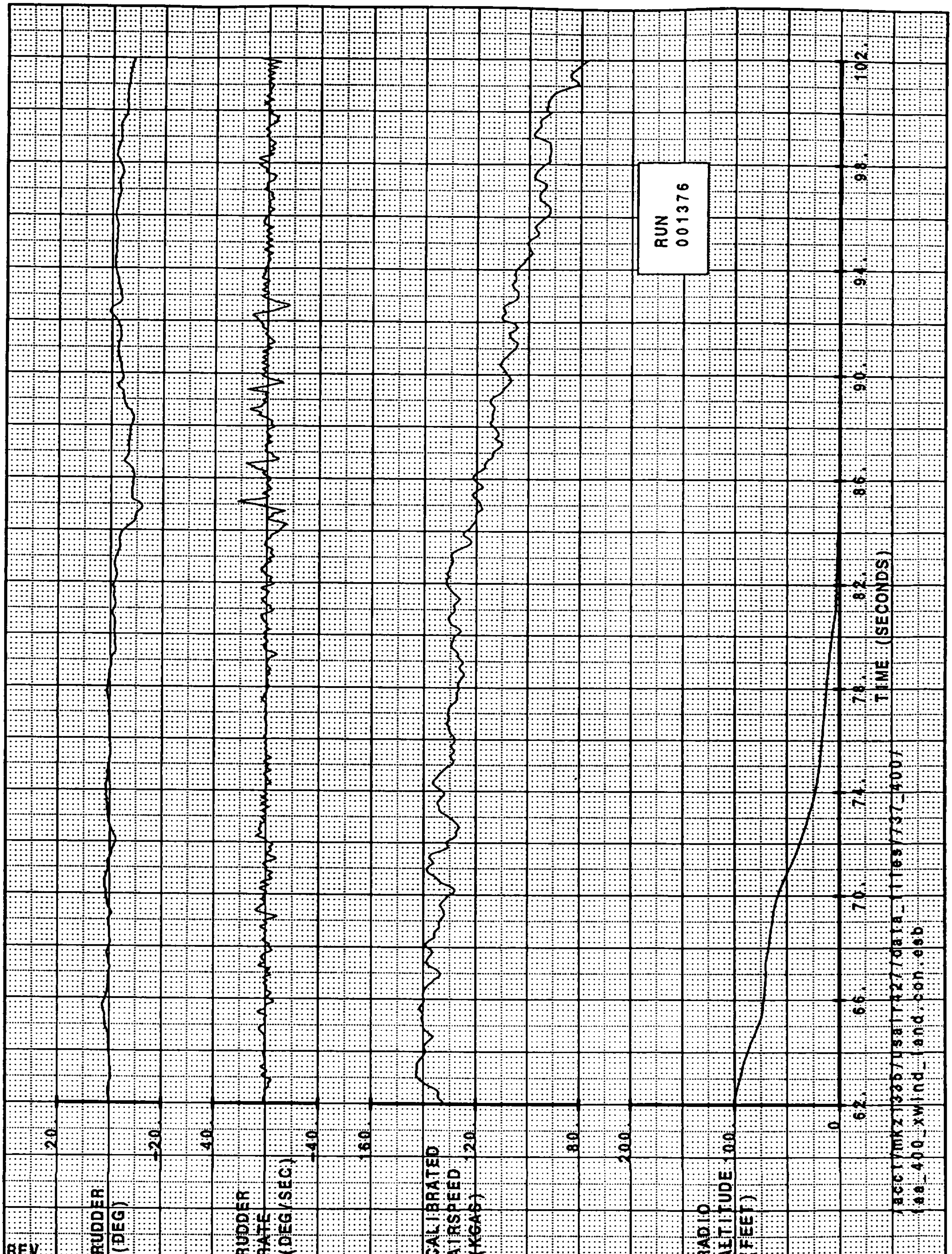


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FIGURE E2.5: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 9 KTS

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737-400

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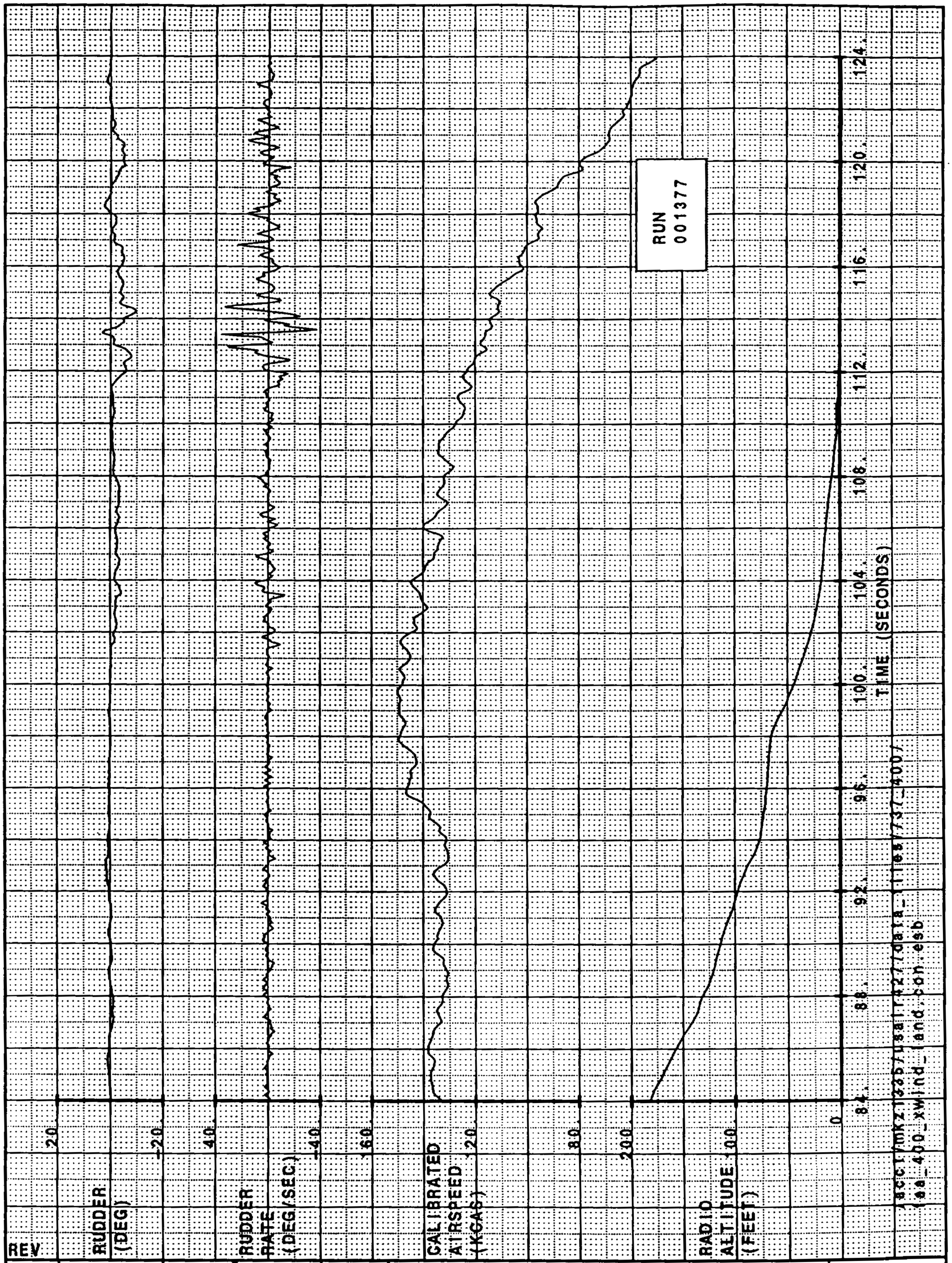


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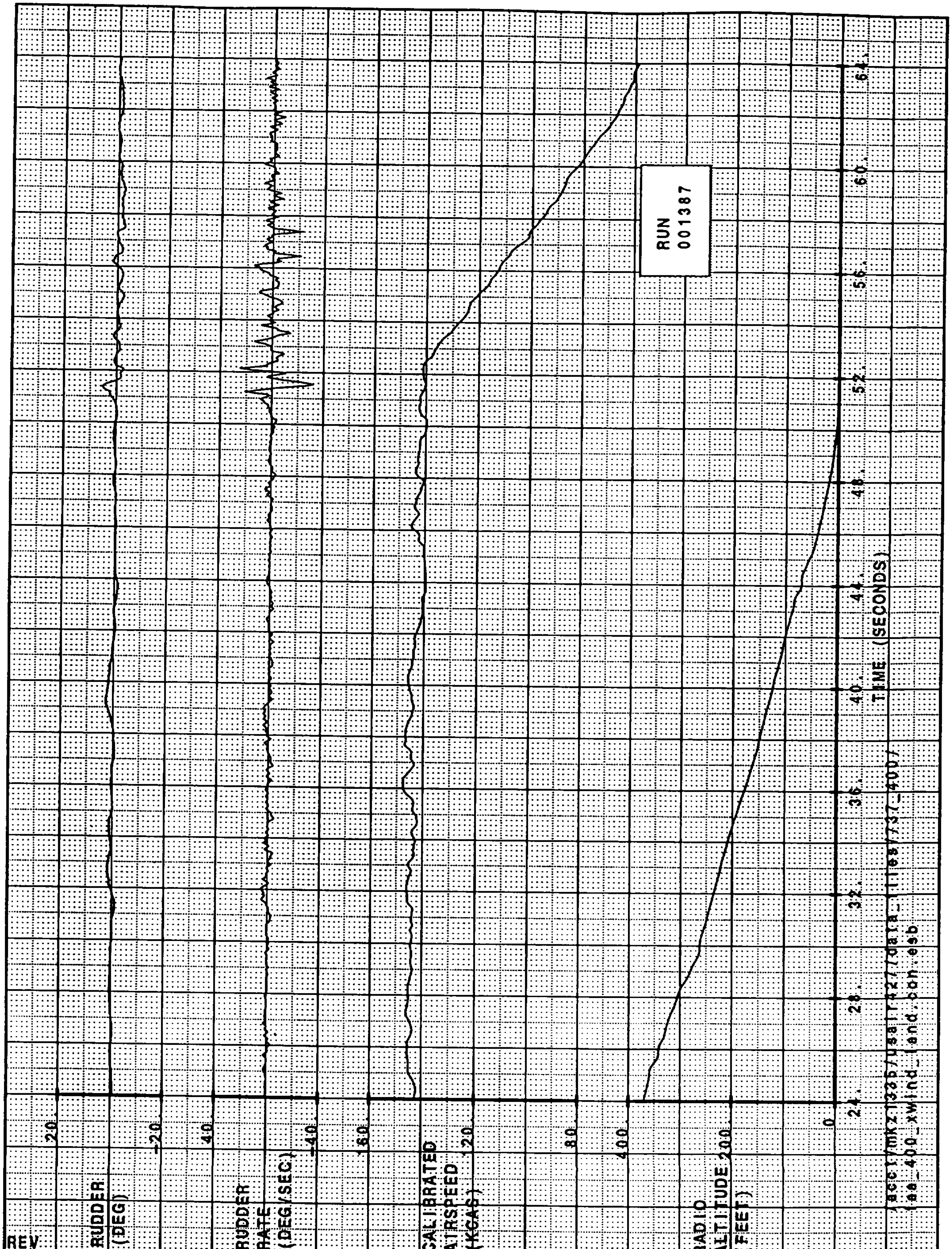


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FIGURE E2.7: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 4 KTS

737-400

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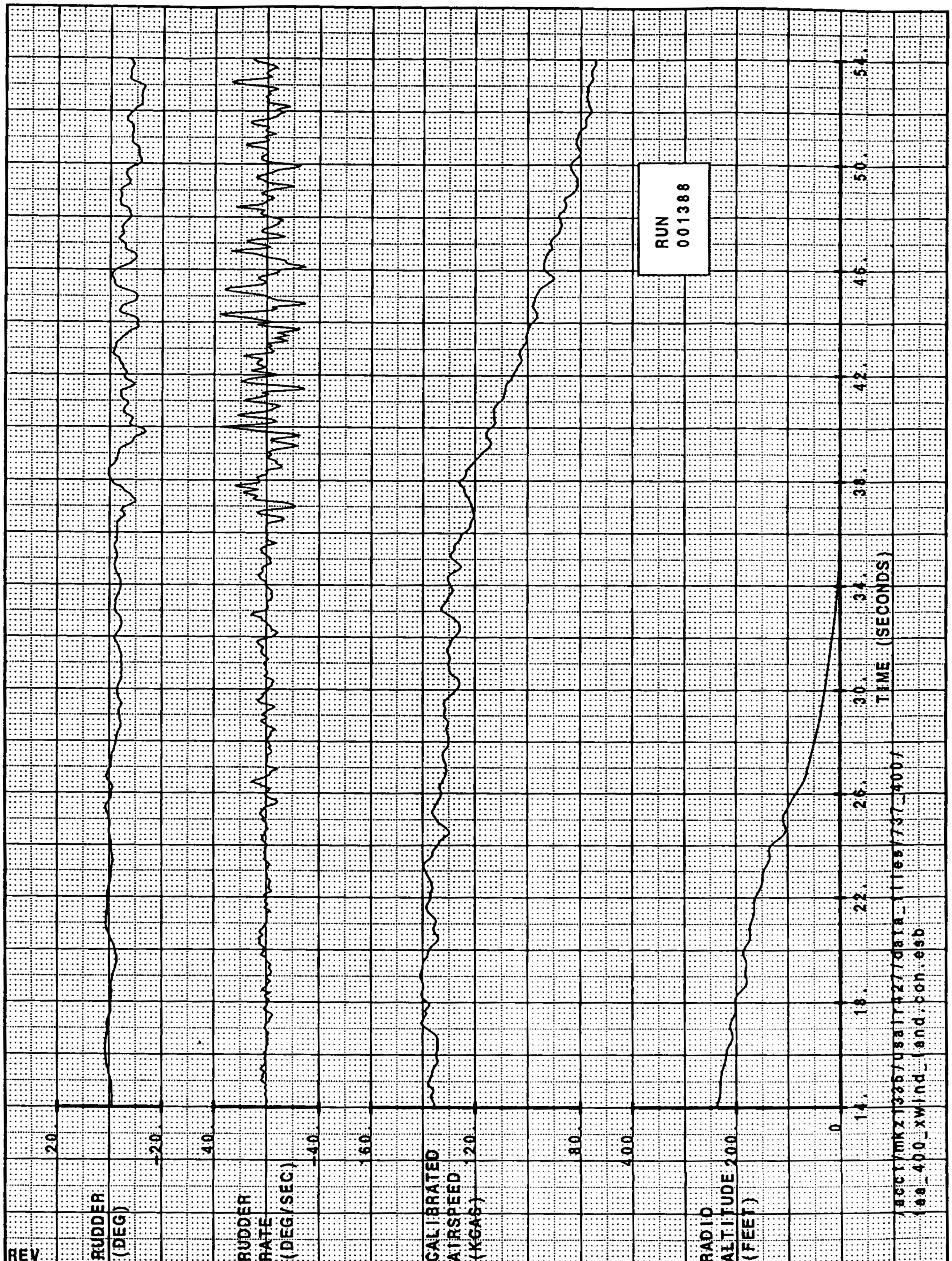
THE BOEING COMPANY

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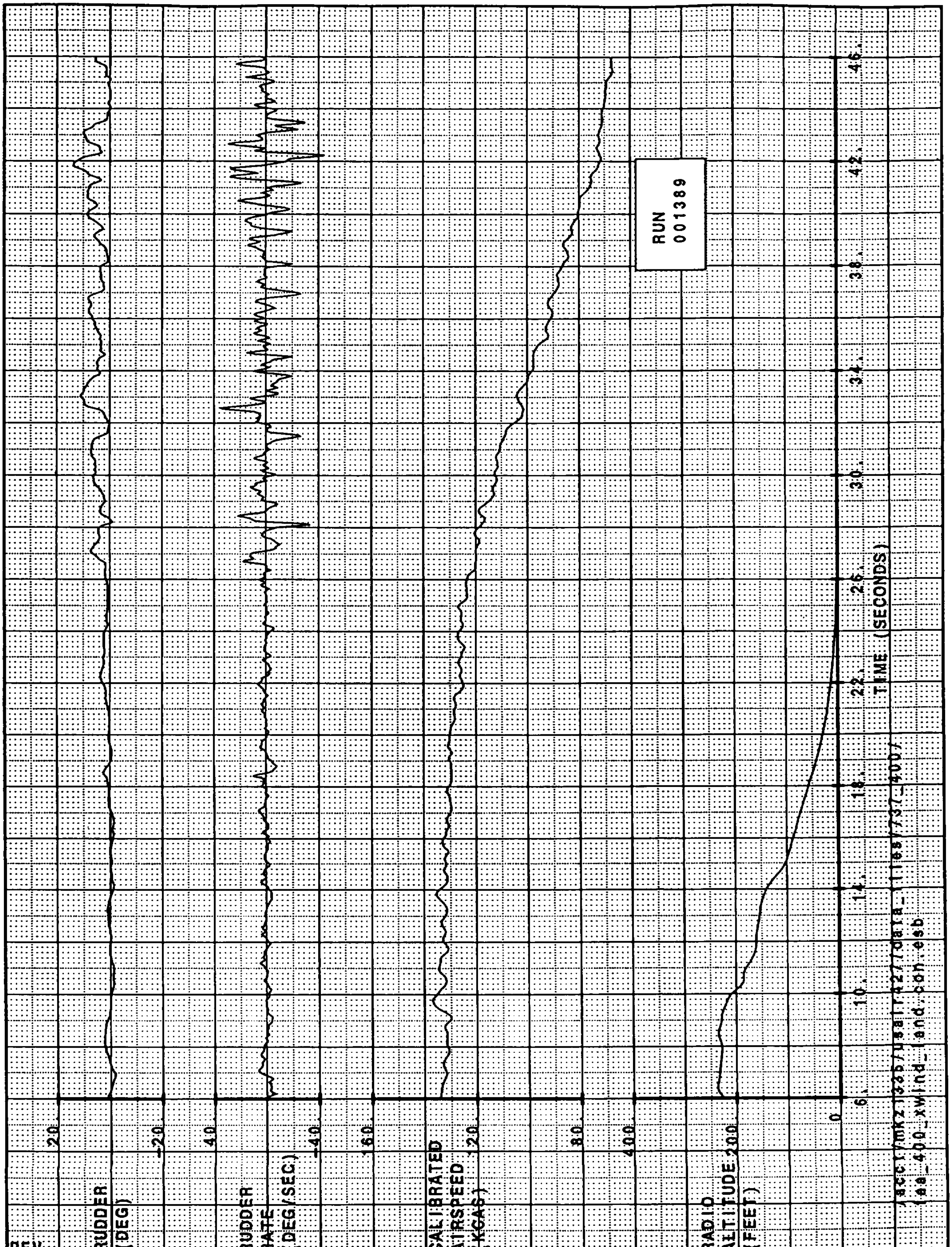


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**FIGURE E2.9: CROSSWIND LANDING FLIGHT TEST RESULTS CROSSWIND COMPONENT = 10 KTS**

737-400

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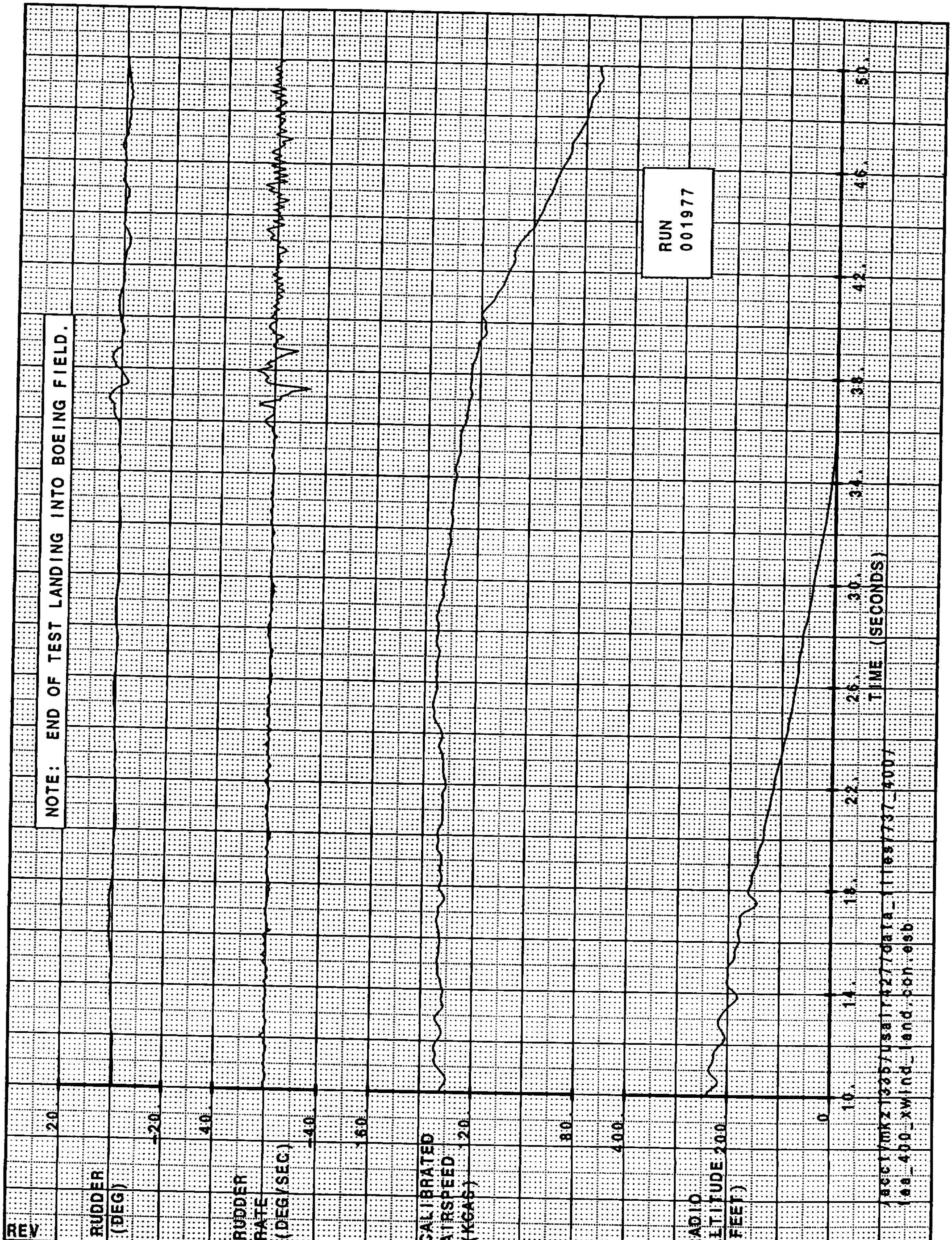
THE BOEING COMPANY

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| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE |
| CHECK | | | | |
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FIGURE E2.10: CROSSWIND LANDING
FLIGHT TEST RESULTS

737-400

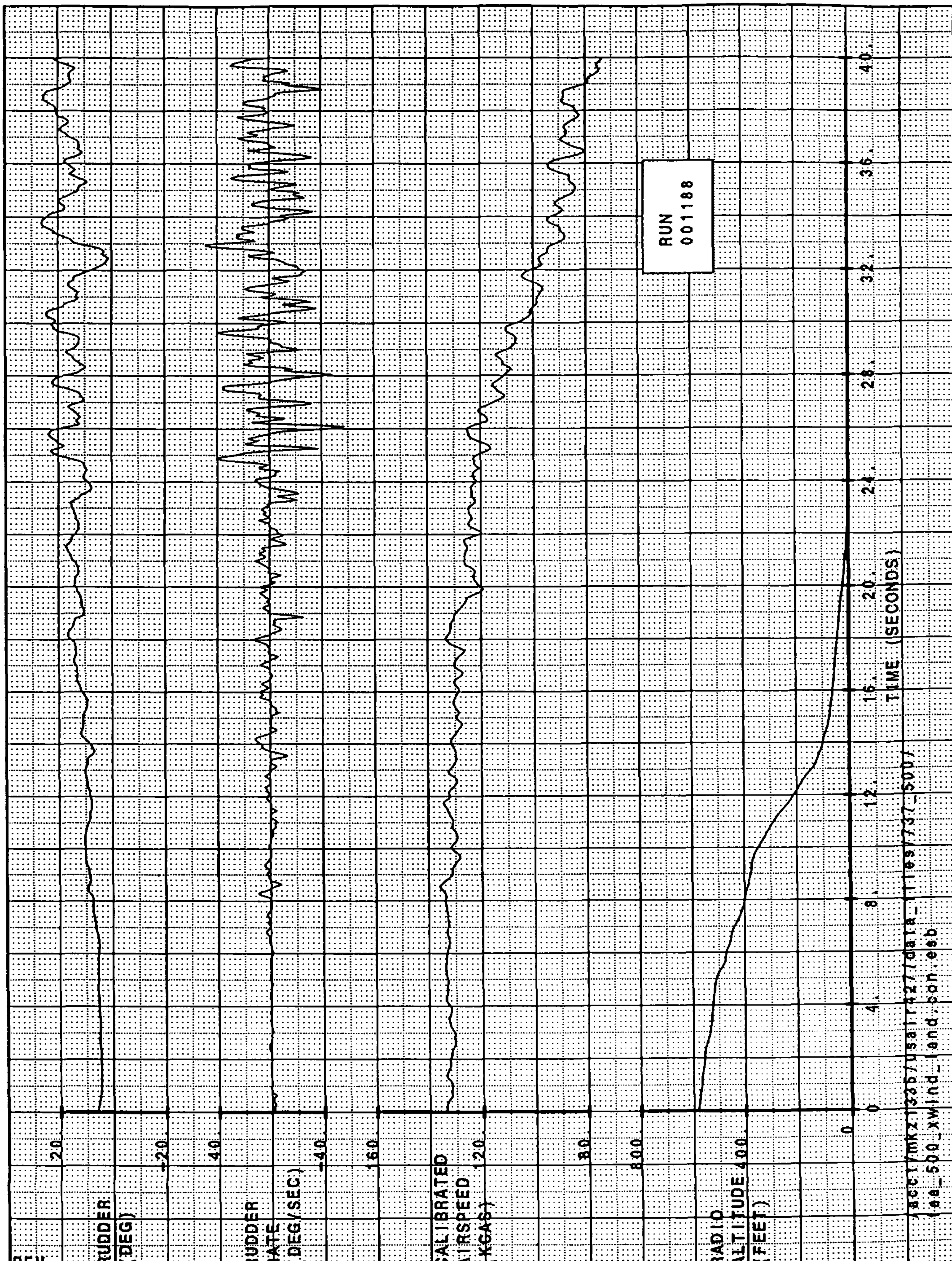
RUN 1977

PAGE

THE BOEING COMPANY

A-3

# ENCLOSURE : FLIGHT TEST CERTIFICATION RESULTS FOR 737-500 CROSSWIND LANDINGS

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| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE |
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FIGURE E3.1: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 33 KTS

THE BOEING COMPANY

737-500

RUN 1188

PAGE

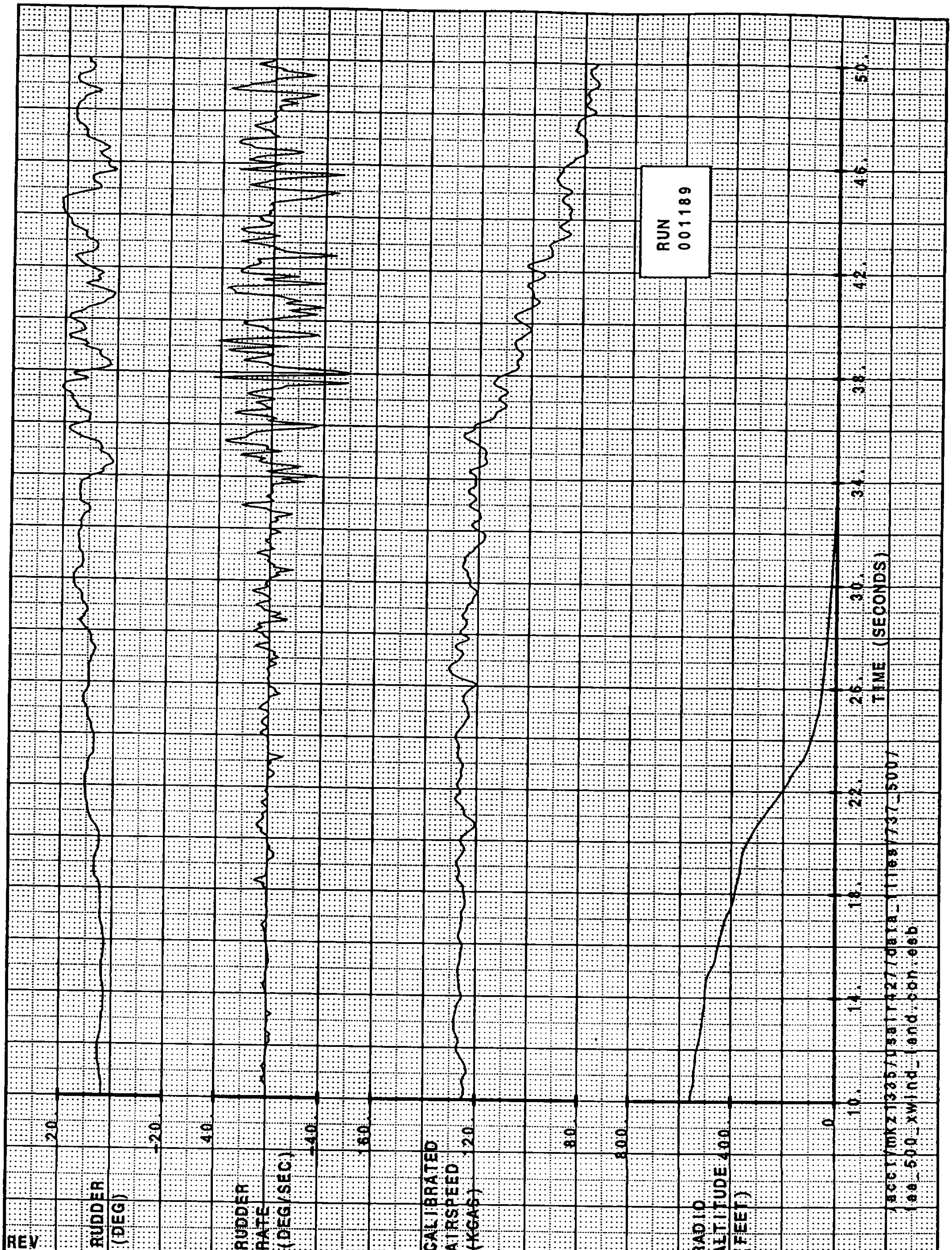


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FIGURE E3.2: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 27 KTS

737-500

RUN 1189

THE BOEING COMPANY

PAGE

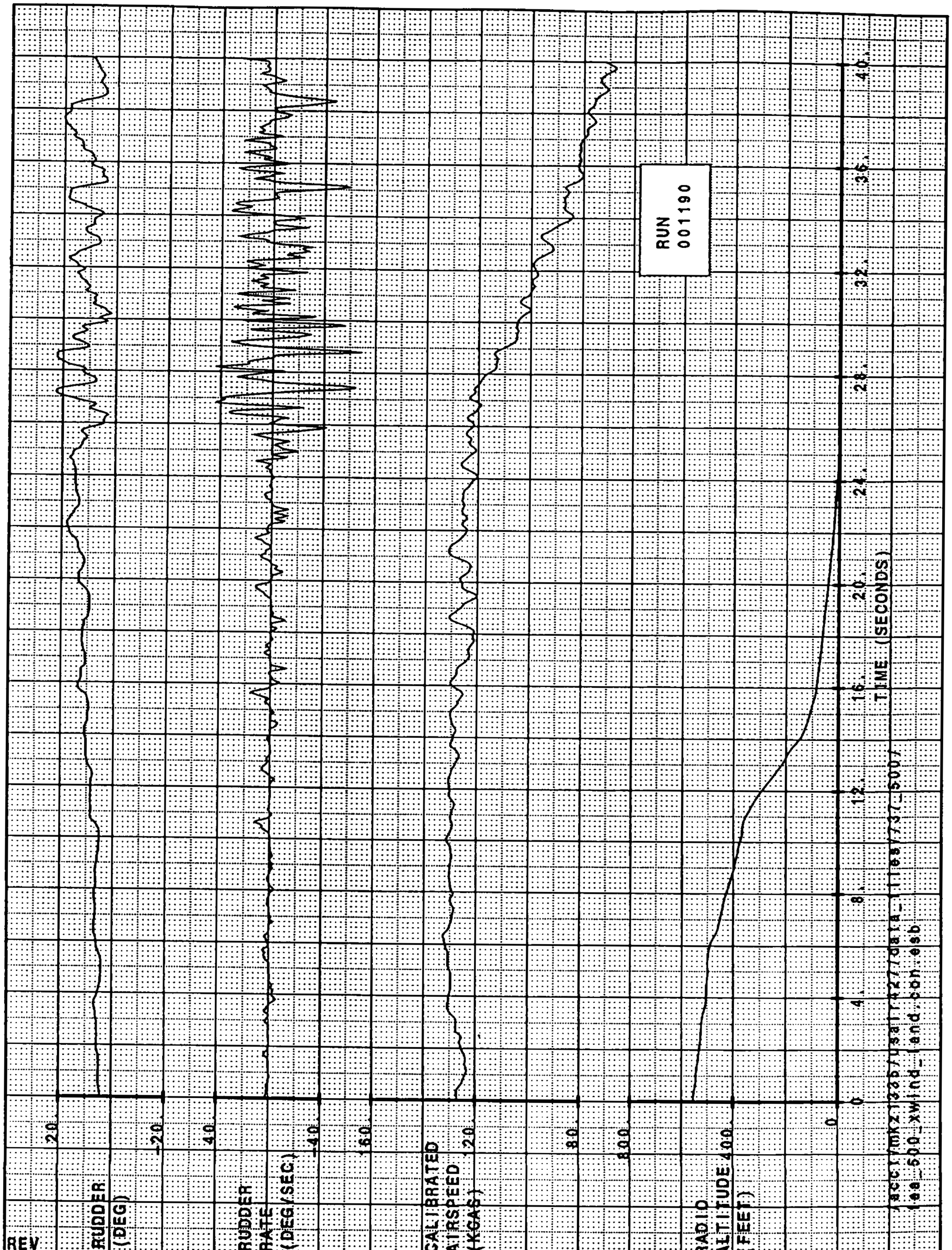


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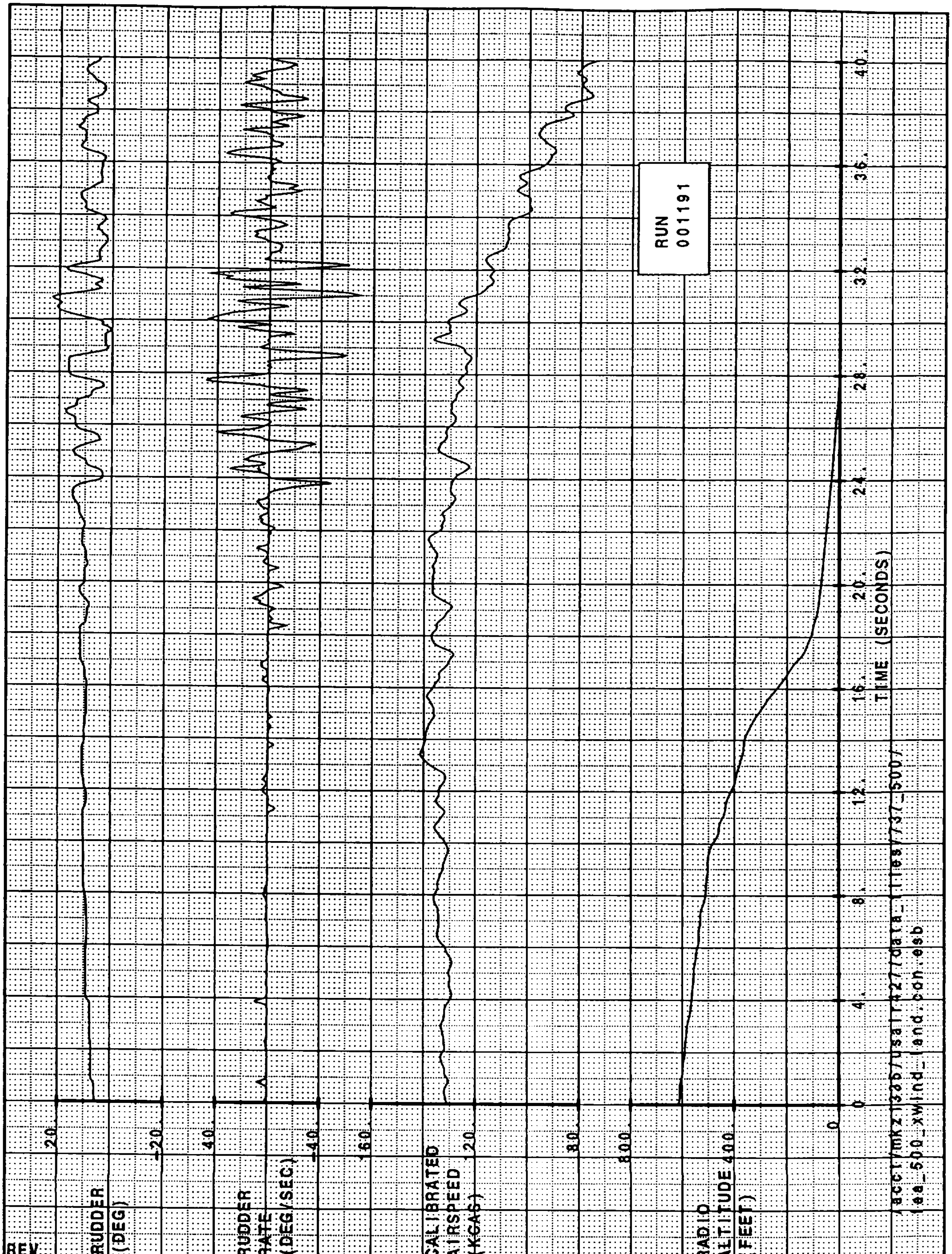
FIGURE E3.3: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 29 KTS

THE BOEING COMPANY

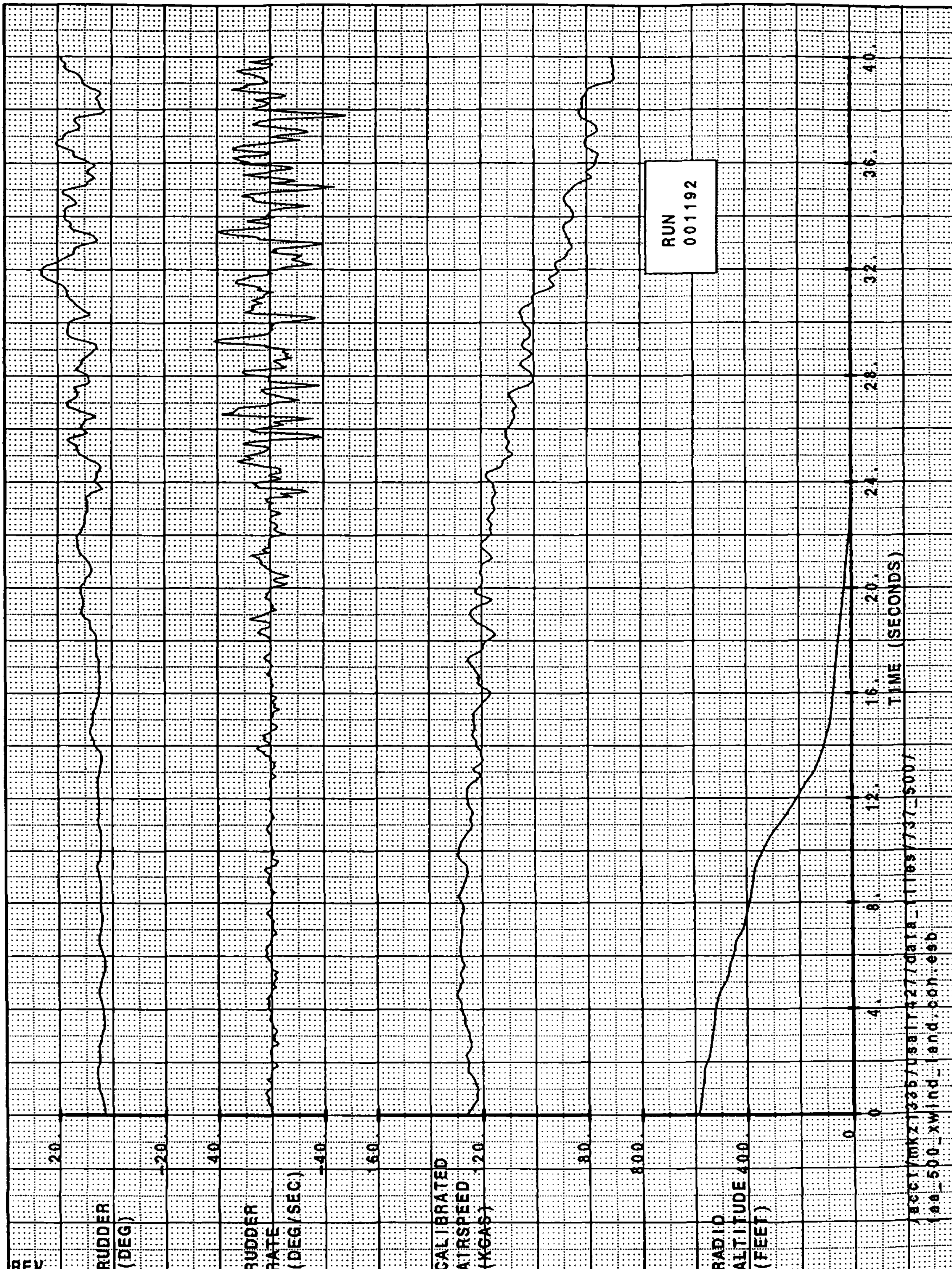
737-500

RUN 1190

PAGE




| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E3.4: CROSSWIND LANDING<br>FLIGHT TEST RESULTS<br>CROSSWIND COMPONENT = 28 KTS | 737-500 |
|---|---|---|---|---|---|---|
| CHECK | | | | | | RUN 1191 |
| APR | | | | | | |
| APR | | | | | THE BOEING COMPANY | PAGE |

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| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E3.5: CROSSWIND LANDING<br>FLIGHT TEST RESULTS<br>CROSSWIND COMPONENT = 29 KTS | 737-500 |
| CHECK | | | | | | |
| APR | | | | | | RUN 1192 |
| APR | | | | | THE BOEING COMPANY | PAGE |

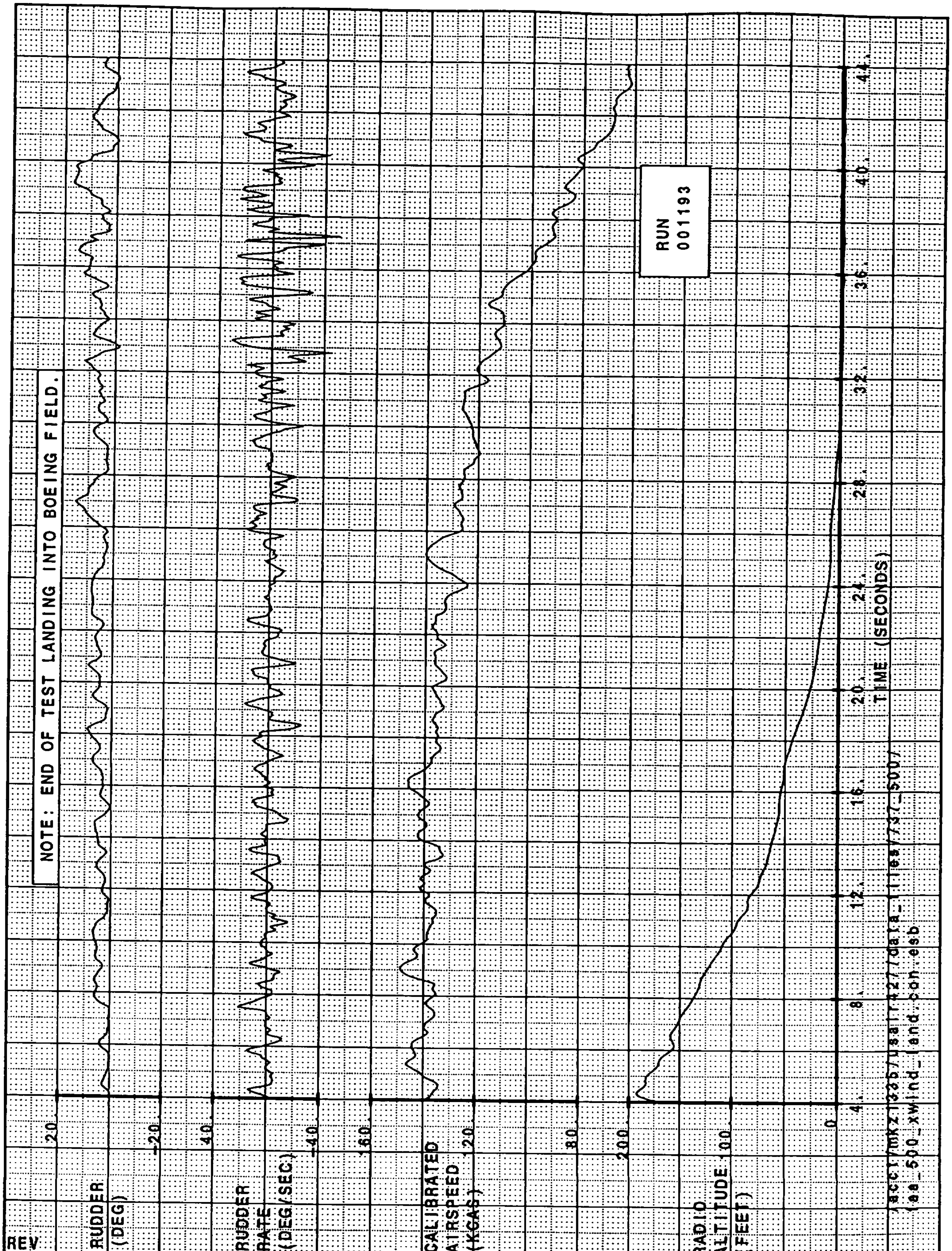


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FIGURE E3.6: CROSSWIND LANDING
FLIGHT TEST RESULTS
CROSSWIND COMPONENT = 11 KTS

737-500

RUN 1193

THE BOEING COMPANY

PAGE

# ENCLOSURE A-4 : FLIGHT TEST RESULTS FOR 737-300 WAKE VORTEX ENCOUNTERS

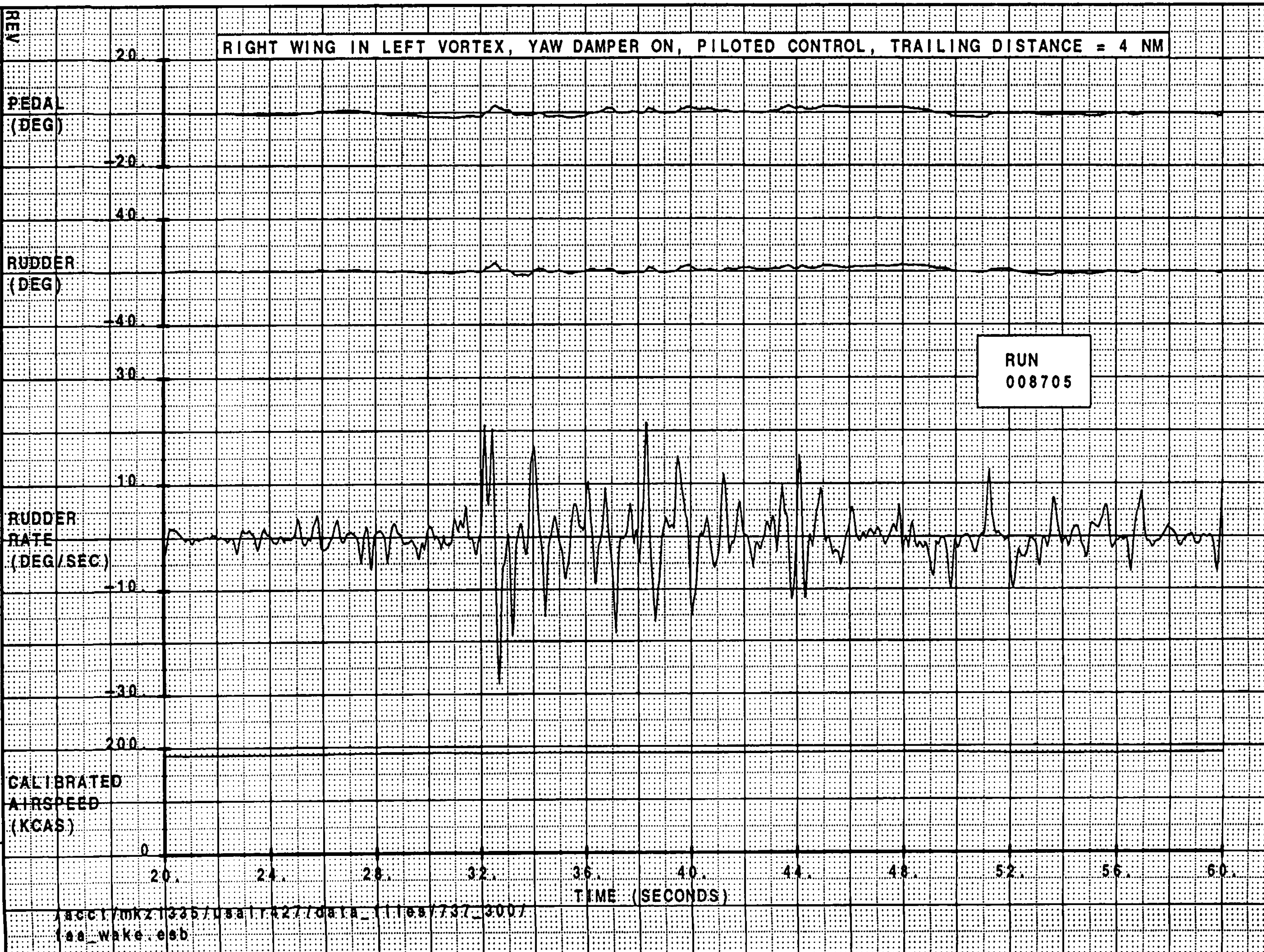


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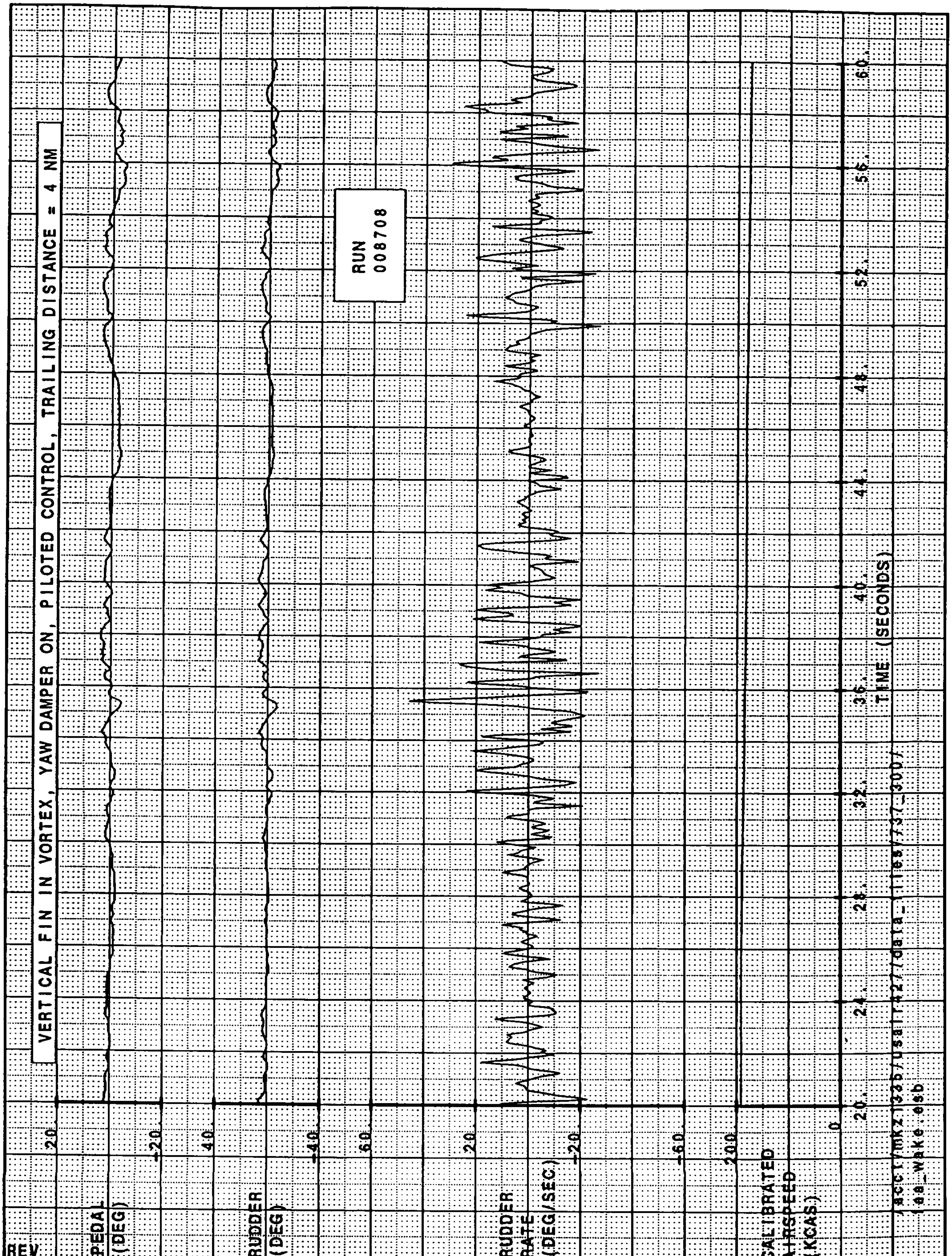
FIGURE E4.1: ATLANTIC CITY WAKE VORTEX ENCOUNTER FLIGHT TEST RESULTS

737-300

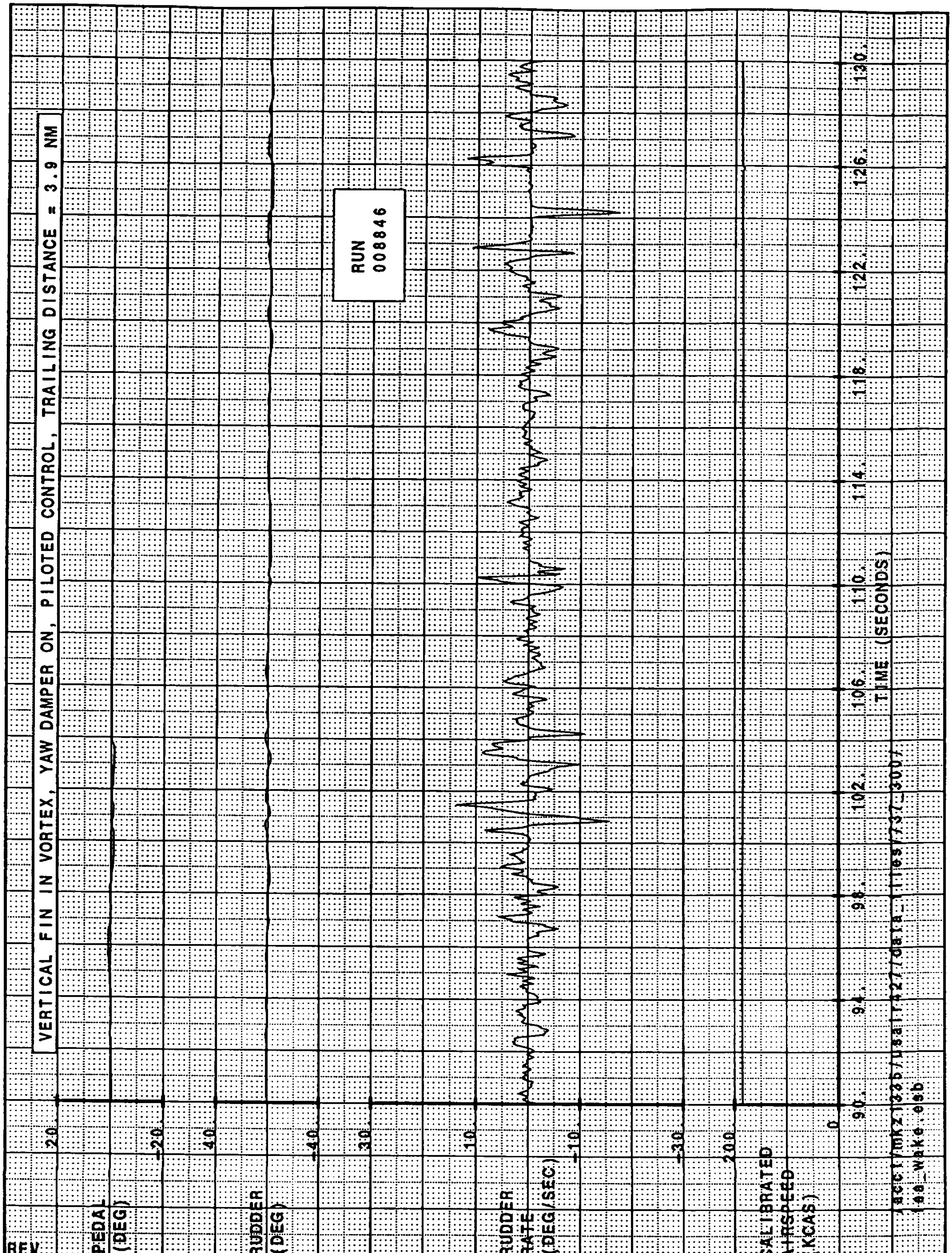
RUN 8705

PAGE

THE BOEING COMPANY




| | | | | | | |
|---|---|---|---|---|---|---|
| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E4.2: ATLANTIC CITY WAKE VORTEX ENCOUNTER FLIGHT TEST RESULTS | 737-300 |
| CHECK | | | | | | |
| APR | | | | | | RUN 8708 |
| APR | | | | | THE BOEING COMPANY | PAGE |




| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E4.3: ATLANTIC CITY WAKE VORTEX ENCOUNTER FLIGHT TEST RESULTS | 737-300 |
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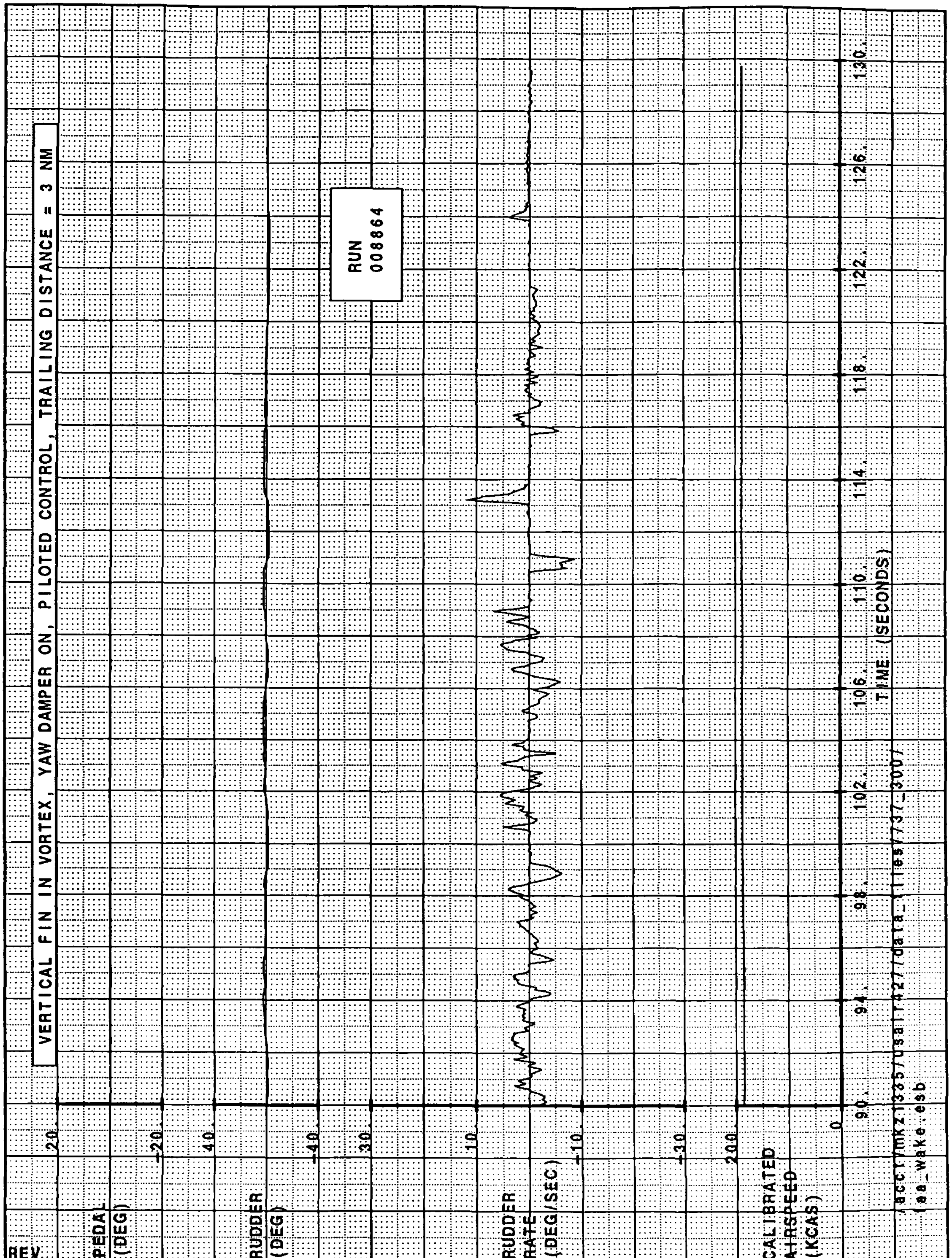
| CHECK | | | | | | |
| APR | | | | | | RUN 8846 |
| APR | | | | | THE BOEING COMPANY | PAGE |




| CALC | M. ZYSKOWSKI | 19MAR97 | REVISED | DATE | FIGURE E4.4: ATLANTIC CITY WAKE VORTEX ENCOUNTER FLIGHT TEST RESULTS | 737-300 |
|---|---|---|---|---|---|---|
| CHECK | | | | | | RUN 8864 |
| APR | | | | | | |
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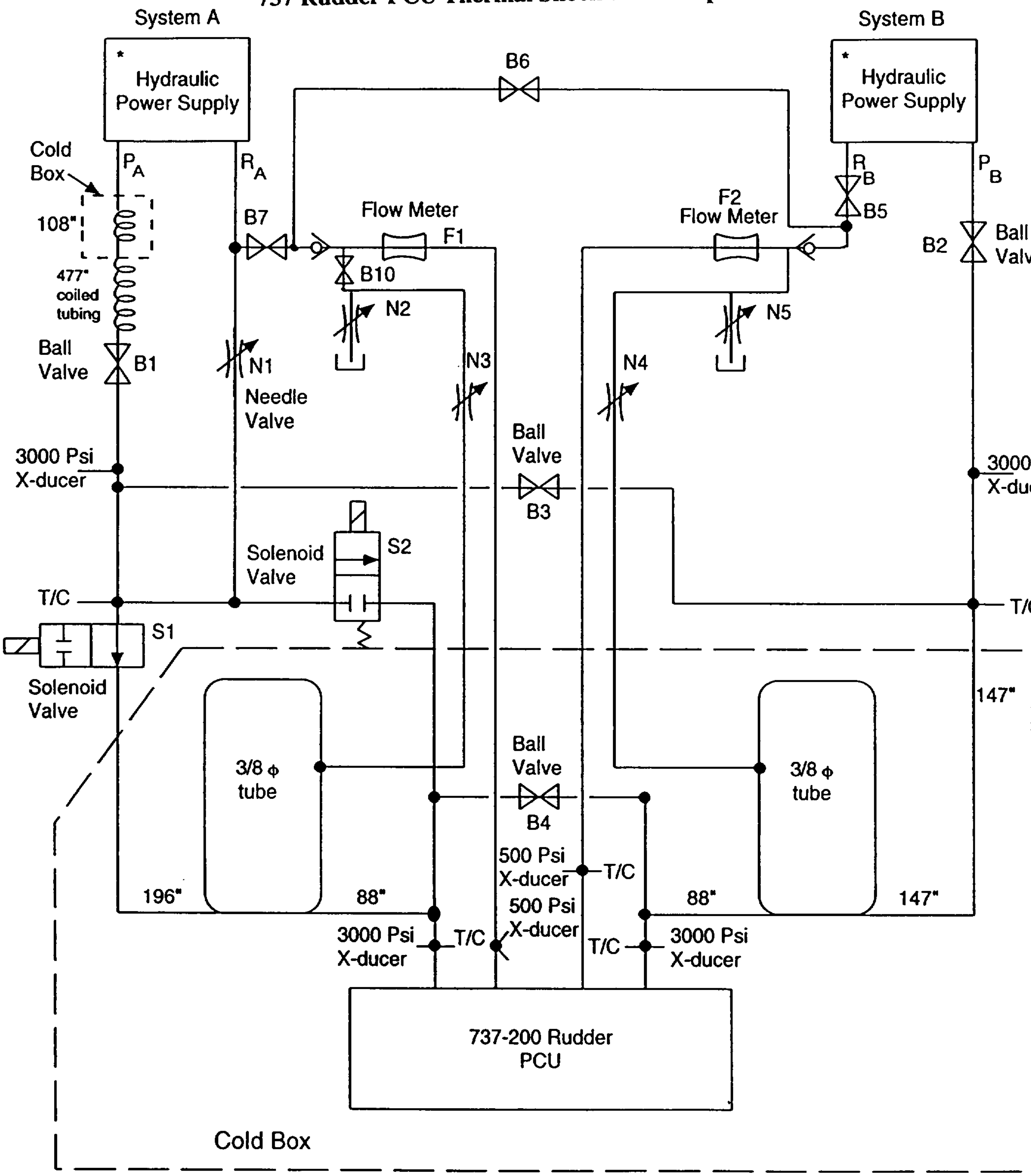
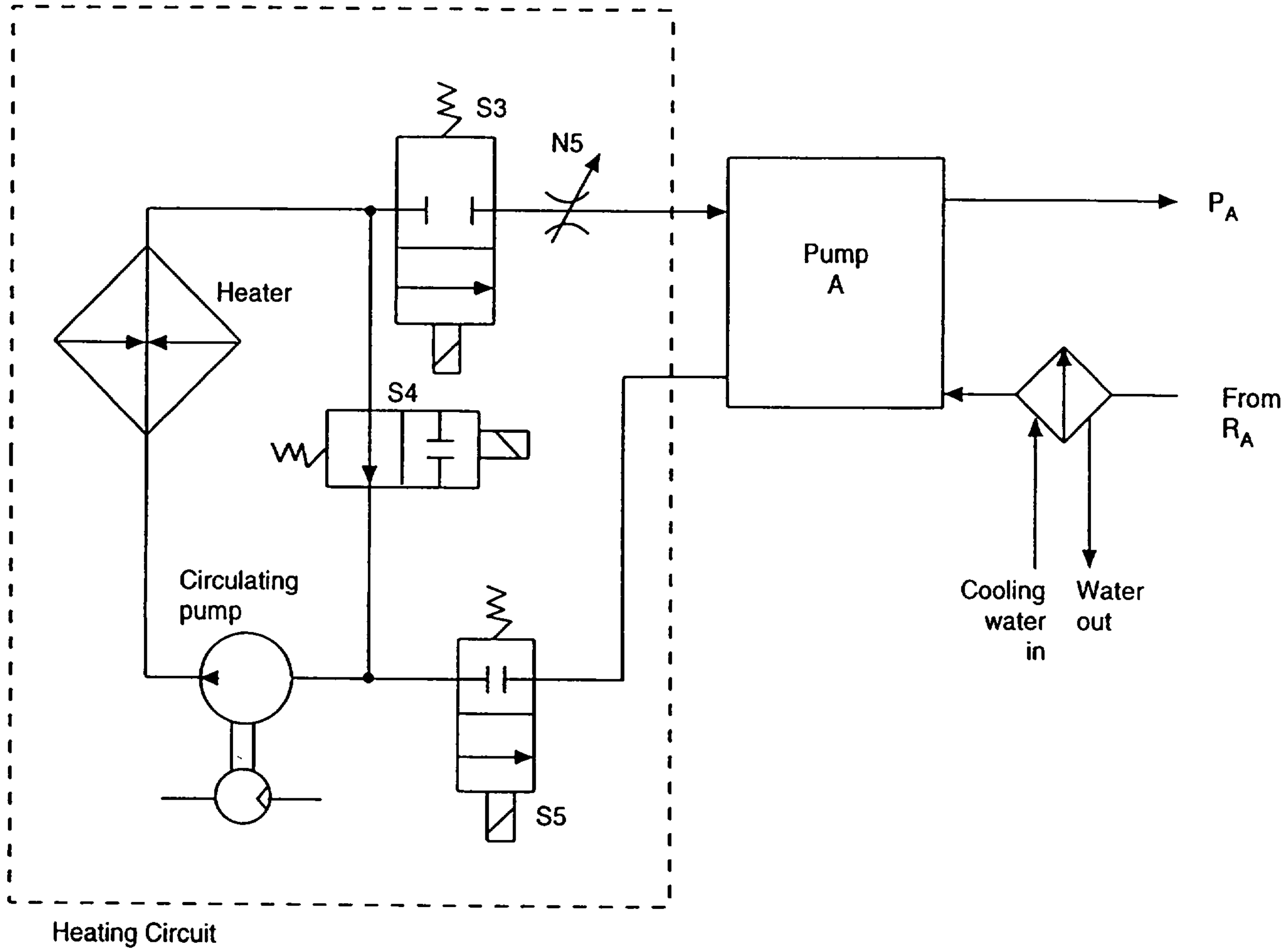
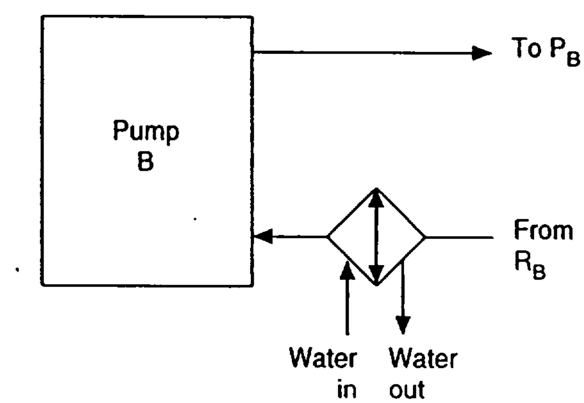
## 737 Rudder PCU Thermal Shock Test Setup Schematics




737-200 Rudder Thermal Shock Test (1)

* See schematics for Hydraulic Power Supply Schematics (2)




737 Rudder Thermal Shock Test
Hydraulic Power Supply Schematics

Kent Space Center
Contamination Laboratory
~~773-8934~~ 657-3844

# Request for Fluid Analysis

(Original to be returned for your records)

97/3/17-5782

Lab Report # 2-4882-033C

☐ HOT SAMPLE: Contact lab 2 hours prior to delivery

Requested by JAMES POTHOVEN Org'n BXT51 M/S 19-HC Phone [redacted] Date 3/13/97

Fluid Type BMS 3-11 Sample Source SYSTEM A, 3/13/97 (#30-03535

Sample Identification SYSTEM A, (3/13/97), (30-03538) ☐ New Fluid ☑ Used Fluid

Job Charge Number SR45213241066F00 (Work Order Number) 8008124 (Salco Number)

| (To be completed by requesting org'n) Analysis Requested | Requirements New | Requirements Used | (To be completed by Lab) Lab Results | | | | | |
|---|---|---|---|---|---|---|---|---|
| Check test requested | | | Size 5-15μ | 16-25μ | 26-50μ | 51-100μ | >100μ | NAS 1638 Class |
| ☑ Microscopic Particle Count/100 ml | | | 313,685 | 38842 | 640 | 15 | 1 | 11 |
| ☑ Total Moisture % by Wt or ppm by Wt | | .313% | | | | | | |
| ☐ Viscosity @ ______ °F | | | | | | | | |
| ☐ Acid Neut No., mg KOH/g | | | | | | | | |
| ☐ Specific Gravity and/or Be 60°/60° | | | | | | | | |
| ☐ Flash Point in °C or °F | | | | | | | | |
| ☐ Other | | | | | | | | |

LAB RESULTS DISPOSITION (Check one)

☑ Call Report Results ASAP FAX 662-0453

☐ Call for Report Pick-up

☐ Mail Report

(To be completed by lab)

[redacted] 3/18/97

Q.A. Lab Signature

Oil Lab, KSC
~~773-5478~~

X-25157 REV 12/86

Enclosure C To BE380-M97-007

# BOEING COMMERCIAL AIRPLANE GROUP

## AIR SAFETY INVESTIGATION

### RAPIDFAX LEAD SHEET

DATE: 25 Feb 97

LEAD + 3 Page(s)

TO: **Greg Phillips**
**NTSB**

**Fax:** [redacted]

FROM: **Rick Howes**

**Fax:** [redacted]

---

Greg,
This is our interim report on the minimum tolerance thermal test.

If you have any questions, please call me.
Thank you,

[redacted]

Rick Howes

# 737 Rudder Power Control Unit (PCU) Thermal Testing Interim Report

As a result of thermal testing of the 737 rudder PCU conducted in the fall of 1996, Boeing is performing additional thermal tests under FAA supervision to allow better understanding of the likelihood of jams of the PCU dual concentric servo valve due to different thermal conditions. Earlier testing, which was conducted at Boeing from October 8-12, 1996, showed that at unrealistic thermal conditions a jam of the secondary slide could result. The current testing was intended to further define the extreme conditions at which a jam could be produced.

The current testing commenced on February 20, using a test configuration that will allow better approximation of airplane system operation. Initial tests have started with a simulated airplane configuration[1] that included the following conditions:

- A servo valve machined to worst-case manufacturing tolerances (most likely to be susceptible to thermally induced jams).

- A simulated hydraulic system failure (probability of occurrence $<10^{-7}$) that resulted in highest expected hydraulic system A temperatures.

- An airplane hydraulic system configuration to approximate maximum leakages at both the elevator and aileron PCU. This was simulated by combining elevator and aileron leakage at the elevator PCU. This test method maximizes the temperature of the hydraulic fluid at the rudder PCU, and most likely exceeds the maximum temperature which would be experienced on an airplane.

- A PCU cold soaked to represent night time temperature conditions at altitude.

These initial test conditions represent a combination of worst-case conditions which are not expected to occur in combination during flight operations.

During this test condition, actuation of the rudder by the yaw damper was normal (no jams occurred). Two full cycles of maximum rate rudder command were then input to the PCU (one cycle is neutral to full right rudder, then to full left rudder, and back to neutral). While two consecutive full cycles of maximum rate rudder input are not ever expected to occur in flight operations, it was understood by the participants that this would be the starting point for testing based on its similarity to testing conducted last fall. These test conditions resulted in a maximum introduction of hot hydraulic fluid into the servo valve, which in turn would cause the greatest possible thermal effect on the valve. After two full cycles of rudder command under these test conditions, the servo valve was induced to jam. It is not known at this time whether the jam involved the primary or secondary valve slides.

The jam condition induced occurred as a result of a combination of worse case system conditions and only for a set of rudder input commands that should never occur in flight. Follow-on tests are being developed that will describe valve jam susceptibility for a combination of more realistic expected operating conditions.

There have been no known reports of flight control anomalies associated with any hydraulic system overheat.

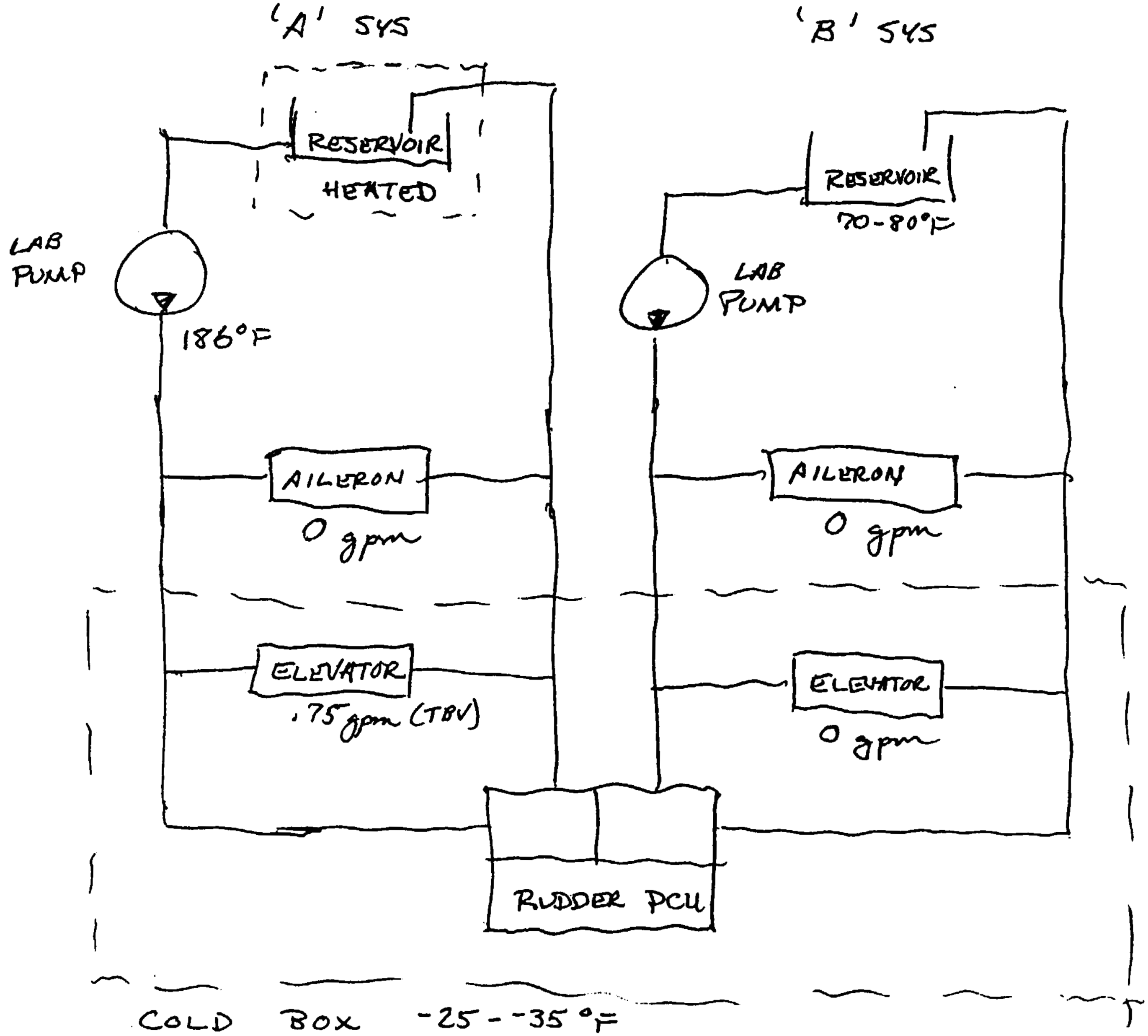
These test results are not related to the USAir accident in Pittsburgh, September 8, 1994, because:

1. The USAir accident rudder PCU did not contain a servo valve machined to worst-case manufacturing tolerances. Testing conducted last October eliminated the possibility of the accident servo valve jamming for any temperature and operating condition that could be experienced in flight.

2. An overheat would have resulted in a master caution indication to the flight crew. There was no discussion of a master caution by the flight crew on the CVR.

1. Enclosure:
   Test Configuration Sketch

# LAB TEST CONFIGURATION



# MEMO

May 21, 1997
BE380-M97-007
Model: 737 -1/2/3/4/500

| | | |
|---|---|---|
| **To:** | K. Buchanan | 9U-RL |
| **cc:** | R. Archung | 02-03 |
| | M. J. Denton | 9X-43 |
| | R. J. Howes | 67-PR |
| | R. A. Kitto | 02-KC |
| | J. McWha | 02-JR |
| | E. A. Pasztor | 02-KE |

**Group Index:** Flight Systems Integration

**Subject:** Test And Analysis Of 737 Rudder Power Control Unit (PCU) Valve Thermal Jam Potential

Please transmit the enclosed report and 8110-3 form to the FAA. This report documents the test and analysis of the thermal jam potential of a 737 rudder power control unit (PCU) with a minimum clearance control valve.

Prepared By: [redacted]
D. S. Wang BE380 for
294-7952 02-KE

Approved By: [redacted] 5/21/97
J. G. Draxler BE380
02-KE

# Test And Analysis Of 737 Rudder Power Control Unit (PCU) Valve Thermal Jam Potential

**Reference** (a) Letter To NTSB B-B600-15972-ASI, 737-1/2/3/4//500 Rudder Power Control Unit (PCU) Thermal Test Report, dated 2/12/97

## Summary

This report covers testing that was conducted at the Boeing Integrated Airplane System Lab (IASL) between February 22 and March 17, 1997, to determine the susceptibility of 737 rudder PCU control valves to thermal jamming. The testing was conducted as a certification test and was witnessed by the FAA.

The testing demonstrated that a minimum clearance valve did not seize under worst case thermal overheat conditions and with the highest level of rudder activity that would be expected in flight. The testing also demonstrated that the valve would not seize for a hot day condition.

The valve did seize for thermal shock conditions that were well beyond any reasonable temperature conditions that could be anticipated in flight. For example, when hot fluid was introduced directly into the PCU after it had been cold soaked while depressurized. The minimum clearance valve seized when the PCU fluid inlet temperature was 140 ° F above the valve housing temperature. Under the same condition, the Flight 427 valve seized at a temperature difference of 175 ° F. This was expected since the minimum clearance valve had smaller diametric clearances for both primary and secondary slides than did the Flight 427 valve.

## Howes, Rickey J

**From:** Howes, Rickey J
**Sent:** Tuesday, June 02, 1998 12:21 PM
**To:** 'Phillips Greg'
**Subject:** RE: Min tolerance test final report

Greg - I will fax you a copy of the text, and overnight the whole document. Please let Pam know. Thanks,
*Rick Howes*

[redacted]

---------

**From:** Phillips Greg(S[redacted]
**Sent:** Friday, May 29, 1998 6:50 AM
**To:** 'Rick Howes'
**Subject:** Min tolerance test final report

Rick,

Could I get a final copy of your min tolerance servo valve test report?

I don't know what was issued and I'd like to see that one gets in our file for the USAir 427 investigation.

Thanks,
Greg