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

July 10, 1995
B-U01B-15305-ASI

Mr. Thomas Haueter, AS-10
National Transportation Safety Board
490 L'Enfant Plaza SW
Washington D.C. 20594

BOEING

Subject: Leading Edge Slat Study USAir 737-300 N513AU Accident Near Pittsburgh - September 8, 1994

Reference: Letter Chairman Hall to John Purvis, action item 13, (hearing) January 27, 1995

Dear Mr. Haueter:

As requested in the reference action item, we are providing below the results of a Boeing study to determine the displacements and loads on the subject slat if the outboard main track was failed. Elfini, ATLAS and ECDKYN, discussed below, are finite element methods used by Boeing for analyzing static and dynamic structural design. The Elfini base module is owned by Dassault Aviation in France, where as, ATLAS and ECDKYN software codes were developed by Boeing and are proprietary.

Using the Computer Aided Three-dimensional Interactive Application (CATIA) geometry, an Elfini finite element model was first created of the slat and supports. The Elfini model was then converted into an ATLAS finite element model, because Elfini does not include non-linear bending effects.

Enclosure A shows the slat geometry. Enclosure B illustrates the slat main track, the slat auxiliary track and the idealization geometry. Enclosures C and D lists the assumptions used in the study. The results shown in Enclosure E are from the ATLAS model. Sheet 1 shows the displacement in inches and sheet 2 shows the loads in kips (thousands of pounds).

The procedure used for the Elfini study was to first determine where the slat would move, if the outboard main track was not there. This was accomplished by inputting a small stiffness for the element defining the outboard main track support. The large displacement, rigid body motion was determined by applying a light load to the slat. In the displaced position, the airloads were then applied to the slat and a linear static analysis performed. For the ATLAS study, a non-linear analysis was performed starting at the intermediate position with the airloads applied.

Aerodynamic loading on the slats was based on flight test measurements with the slat in the intermediate position. To make use of the data, the assumption was made that the effects of a degree of slat twist angle on slat aerodynamics was equivalent to a degree of change in airplane angle of attack. The aerodynamic load was allowed to increase to the maximum normal force coefficient sustainable by the slat during the flight test, and then it was held at that level as the slat twisted further.

The load acting on the outboard auxiliary track (at SS 374.82) obtained from the ATLAS static finite element model analysis was 270% of the ultimate design load with the slat in the fully extended position. Based on a stress analysis performed, the auxiliary track was found to have a negative margin of 40%. Dynamic effects, side loads, and changes in slat orientation would reduce the margin further.

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To assess the effects of the main track suddenly failing in flight, an analysis was performed using ECDDYN. The kinematics of the tracks and actuator were defined in ECDKYN and the stiffness of the slat was based on the Elfini model idealization. This allowed the dynamic response of the structure to be evaluated and then the results brought back into Elfini to obtain the internal loads in the elements of the finite element model. This dynamic analysis resulted in loads on the auxiliary track that exceeded the static loads by a factor of 50%.

Based on the static and dynamic analysis performed, if the outboard main track were to fail in flight, the resulting loads significantly exceed the capability of the remaining support structure and the subject slat would depart from the wing.

If you have any questions, please contact me.

Very truly yours,

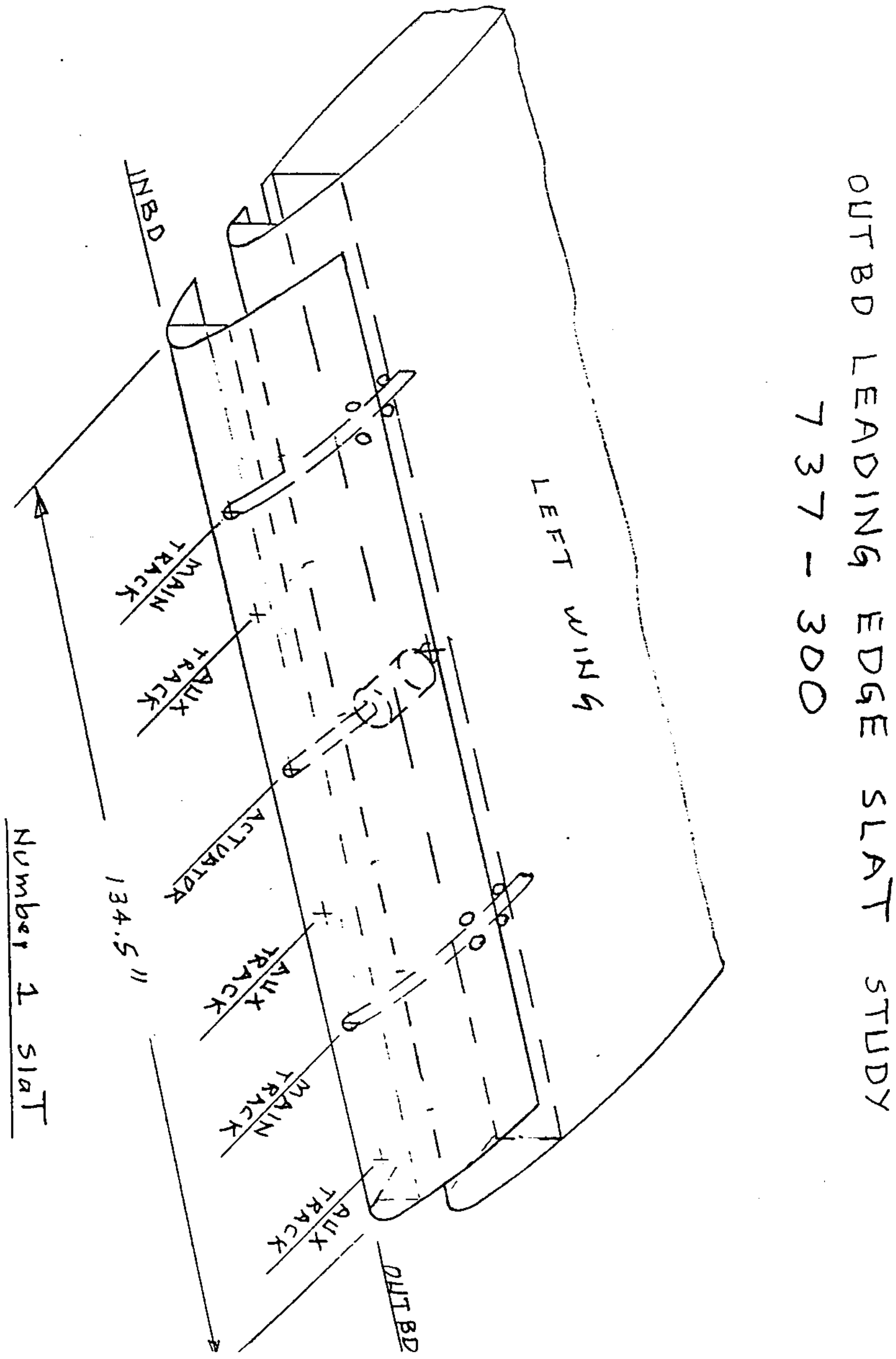
FLIGHT TEST

[redacted]

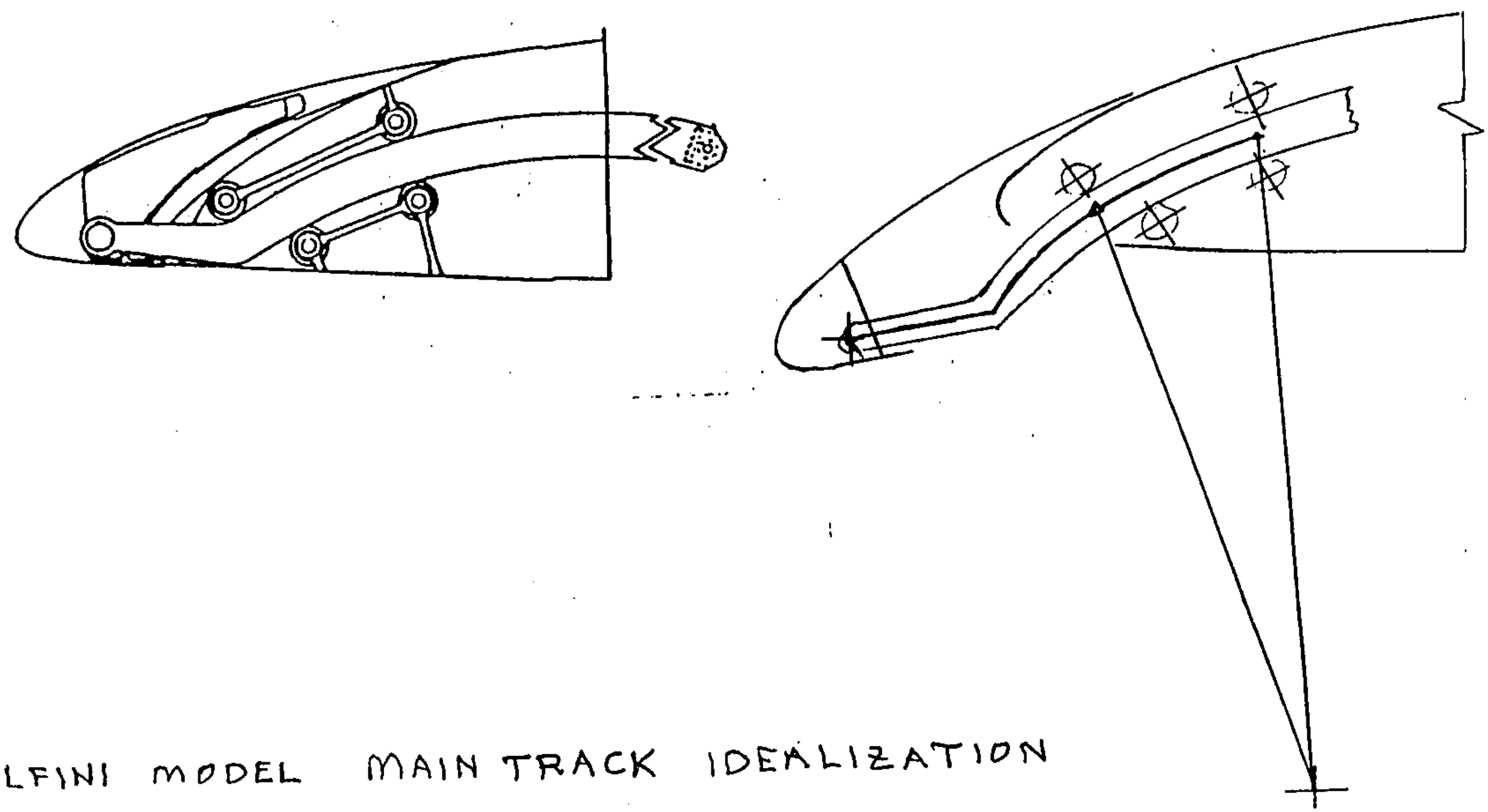
for John W. Purvis
Director, Air Safety Investigation
Org. B-U01B, Mail Stop 14-HM
Telex 32-9430, STA DIR PURVIS
[redacted]

Enclosures:

A Arrangement of the tracks and actuator
B Finite element model idealization of the structure
C Air load assumptions
D Analysis method and assumptions
E Resulting displacements and loads

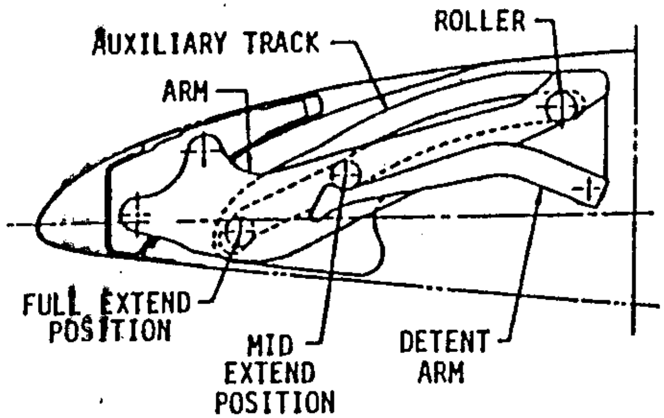

OUTBD LEADING EDGE SLAT STUDY
737 - 300
LEFT WING
INBD
MAIN TRACK
AUX TRACK
ACTUATOR
AUX TRACK
MAIN TRACK
AUX TRACK
OUTBD
134.5"
Number 1 slaT

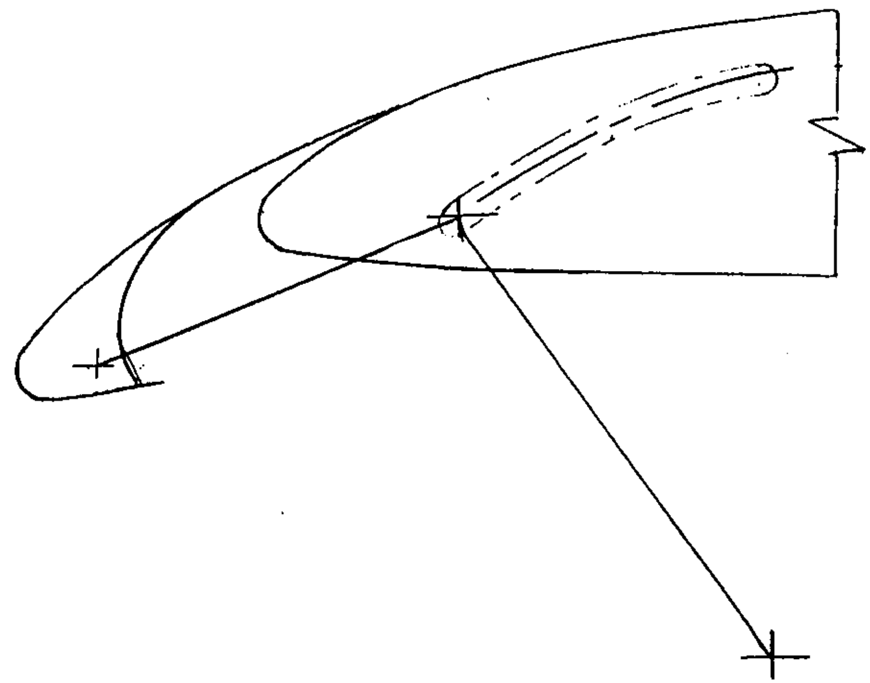
OUTBD LEADING EDG SLAT STUDY
737 - 300



ELFINI MODEL MAIN TRACK IDEALIZATION

OUTBD LEADING EDGE SLAT STUDY
737-300



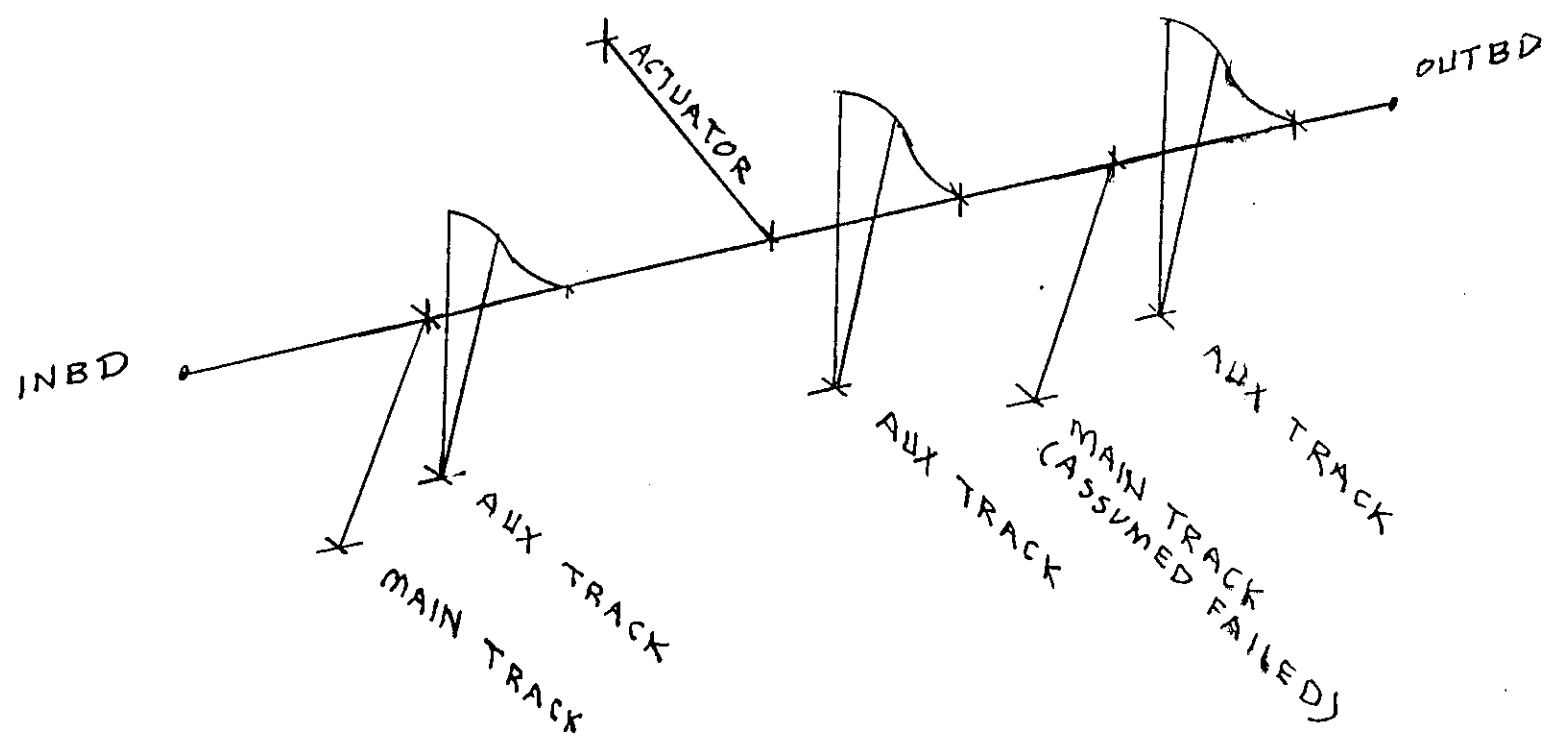


ELFINI MODEL AUXILIARY TRACK IDEALIZATION

OUTBD LEADING EDGE SLAT STUDY
737 – 300

L.E. SLAT IDEALIZATION

(ELFINI & ATLAS F.E.M.)



OUTBD LEADING EDGE SLAT STUDY
737-300

- AIRLOADS
  - LIFT COEFFICIENTS BASED ON FLIGHT TEST DATA.

- ASSUMPTIONS
  - ONE DEGREE OF SLAT ROTATION DUE TO STRUCTURAL DEFLECTION IS EQUIVALENT TO ONE DEGREE OF CHANGE IN AIRPLANE α FOR DETERMINING SLAT LOADS.
  - ONLY SLAT SEALED DATA WAS USED.
  - LOAD COEFFICIENTS WERE ALLOWED TO REACH MAX MEASURED AND THEN HELD CONSTANT.
  - NO ATTEMPT WAS MADE TO ACCOUNT FOR AFFECTS OF SLAT TRANSLATION ON AERO FORCES.

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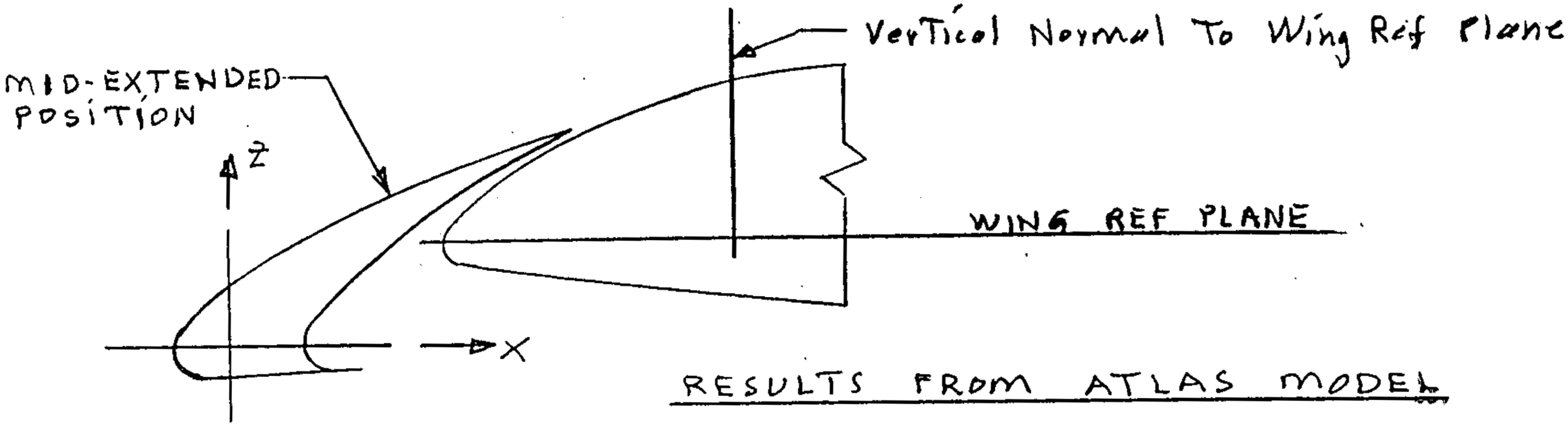
OUTBD LEADING EDGE SLAT STUDY
737-300

- METHODS AND ASSUMPTIONS
  - ELFINI, ATLAS, & ECKDYN MODELS WERE CREATED. MODELS INCLUDED REPRESENTATION FOR THE AUX TRACK, MAIN TRACK AND ACTUATOR.
  - OUTBOARD MAIN TRACK PRESUMED FAILED.
  - AIRLOADS LIMITED TO 3.4 PSI MAX AFTER SLAT REACHED SUFFICIENT ROTATION TO STALL.
  - STIFFNESS AND DEFLECTIONS OF WING BOX SUPPORT STRUCTURE NOT INCLUDED IN ANALYSIS.
  - SLAT INITIALLY LOCATED AT INTERMEDIATE POSITION FOR START OF ANALYSIS.

ENCLOSURE D TO BU01B-15305-ASI

OUTBD LEADING EDGE SLAT STUDY
737-300



RESULTS FROM ATLAS MODEL

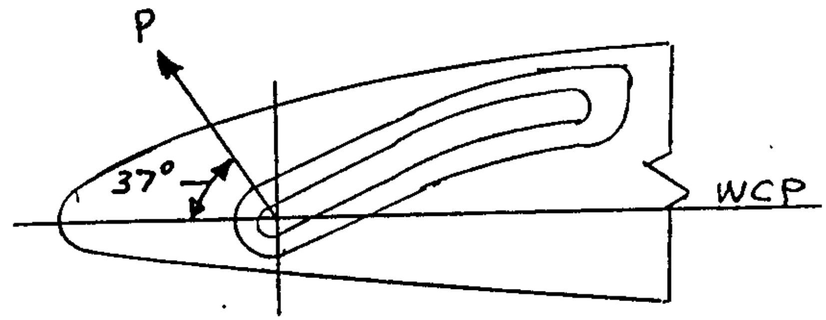
LOCATION	DISPLACEMENT [1] X	Y [2]	Z	ROTATION (DEGREES)
INBD END	4.4	-.4	2.9	15.2°
OUTBD END	-4.0	-.7	4.4	20.2°

[1] measured in Wing Ref Coord. System. Initial Ref position was slat at Mid-Extended Position

[2] Positive outbd - Parallel To Wing Front spar

ENCLOSURE E TO BU01B-15305-ASI

OUTBD LEADING EDGE SLAT STUDY
737-300



OUTBD AUXILIARY TRACK

CONDITION	P AUX TRACK LOAD	
UIT Design	1.27 KIPS	
Slat Study (Failed Main Track)	3.56 KIPS	(ATLAS RESULTS)