The Boeing Company

Terrain Avoidance

The Boeing Company conducted an escape maneuver aerodynamic study and a flight simulator pilot human factors study. These studies and other information formed the basis for the terrain avoidance procedure.

Contents:

1. Terrain Avoidance procedure.
2. Boeing Aerodynamic study results.
3. Boeing flight simulator pilot human factors study results.

The material contained in this Boeing appendix is considered correct and accurate; however, since it is intended to be informative only, it should not be consulted in lieu of official operations manuals.

TERRAIN AVOIDANCE

The following is immediately accomplished by recall whenever the threat of inadvertent contact with the terrain exists. Any of the following conditions is regarded as presenting a potential for terrain contact:

- Activation of the "PULL UP" warning.
- Other situations resulting in unacceptable flight toward terrain.

PILOT FLYING	PILOT NOT FLYING
• Disconnect autopilot • Disconnect autothrottle(s) • Aggressively apply maximum* thrust • Roll wings level and rotate at a rate of 3° per second to an initial pitch attitude of 20° • Retract speedbrakes • If terrain remains a threat, continue rotation up to the pitch limit indicator (if available) or stick shaker or initial buffet	• Assure maximum* thrust • Verify all required actions have been completed and call out any omissions
• Do not change gear or flap configuration until terrain separation is assured • Monitor radio altimeter for sustained or increasing terrain separation • When clear of the terrain, slowly decrease pitch attitude and accelerate	• Monitor vertical speed and altitude • Call out any trend toward terrain contact

NOTE: Aft control column force increases as the airspeed decreases. In all cases, the pitch attitude that results in intermittent stick shaker or initial buffet is the upper pitch attitude limit. Flight at intermittent stick shaker may be required to obtain positive terrain separation. Smooth, steady control will avoid a pitch attitude overshoot and stall.

NOTE: Do not use Flight Director commands.

* Maximum thrust means "maximum certified thrust". On engines without electronic thrust limiting capability, overboost or "firewalling the thrust lever" should only be considered during emergency situations when all other available actions have been taken and terrain contact is imminent.

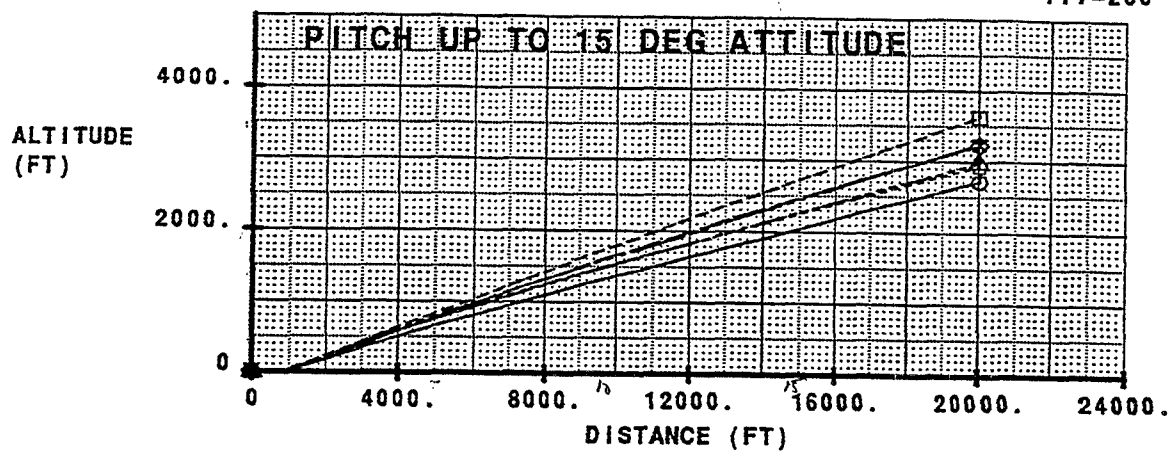
Boeing Aerodynamic Study Results

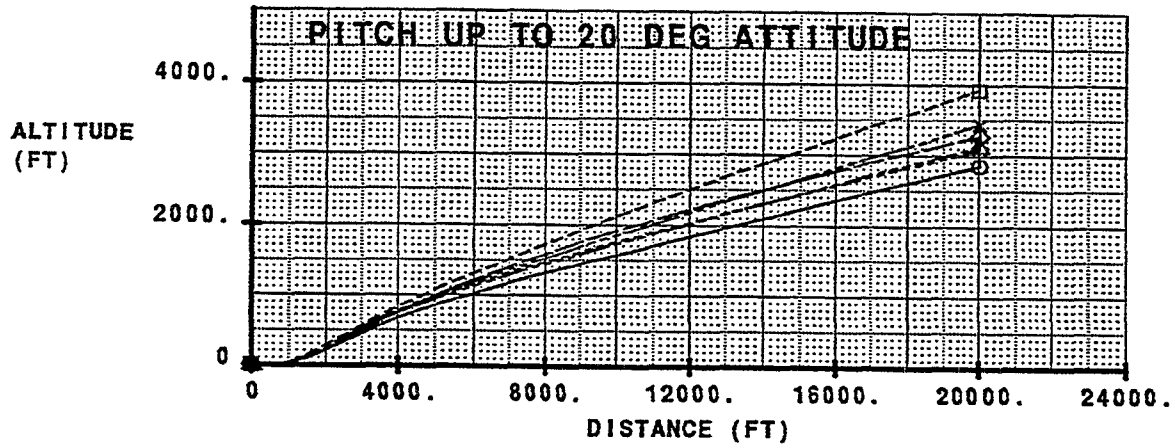
The aerodynamic study evaluated a set of pull-up maneuvers to avoid terrain after receiving a ground proximity warning. The parameters used for the study were three pitch attitudes or angle of attack, two pitch rates, two initial altitudes, and four flap configurations. Figures 1-12 show each plot in various configurations for various Boeing models. Altitude (ft) is graphed on the vertical axis and distance traveled (ft) is graphed on the horizontal axis.

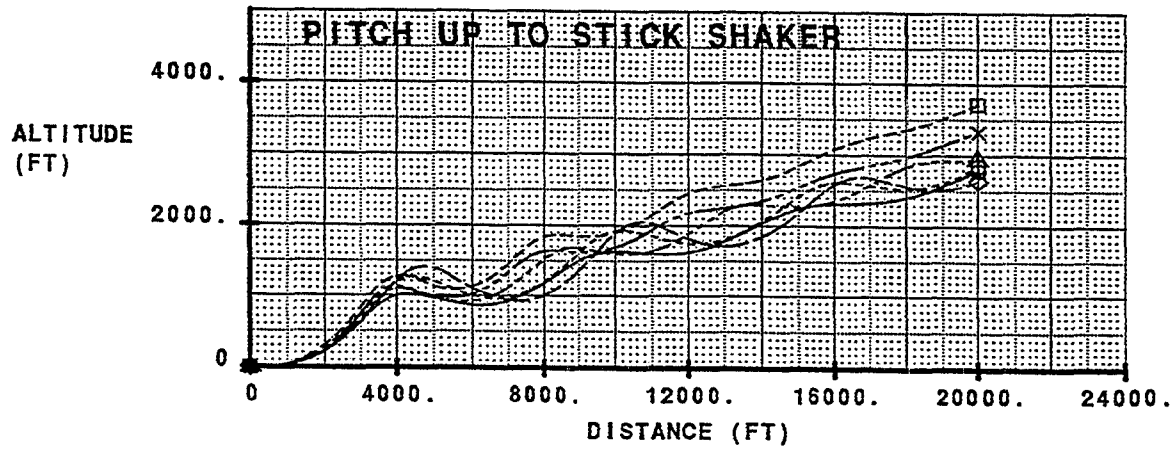
LANDING FLAPS, SEA LEVEL

MAXIMUM LANDING WEIGHT, LANDING GEAR DOWN, VREF +5 KNOTS, MAXIMUM THRUST APPLIED .5 SEC AFTER MANEUVER START, SPEED TRIM OPERATIVE WHERE APPLICABLE

727-200
737-300
747-400
757-200
767-300ER
777-200







CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Landing Flaps at Sea Level 3 Deg/Sec Pitch Rate	VARIOUS MODELS
CHECK						Figure 1
APR					THE BOEING COMPANY	PAGE
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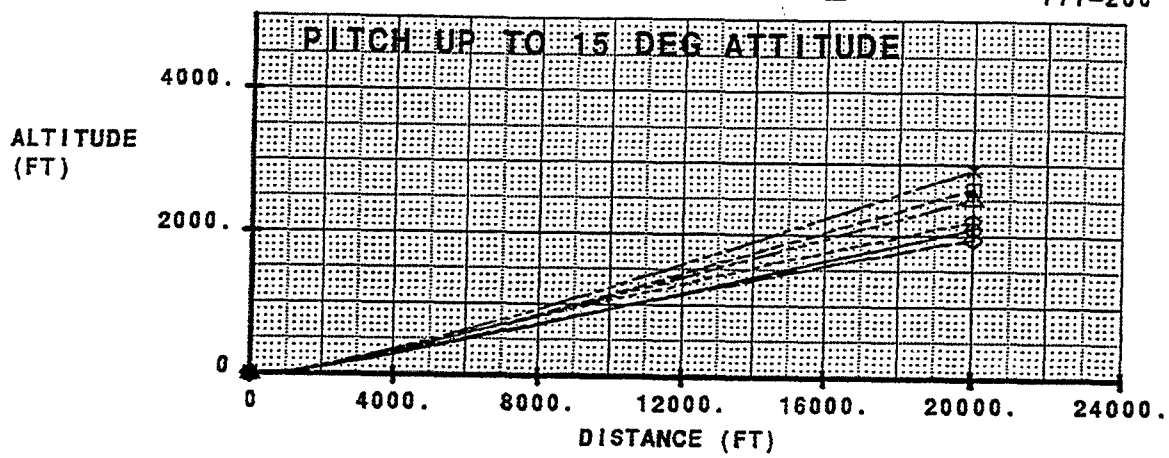
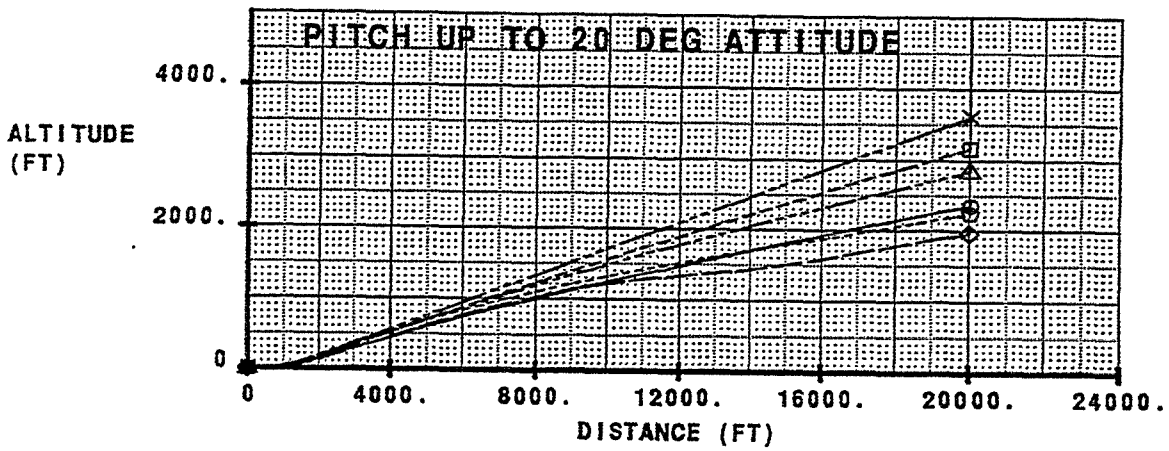
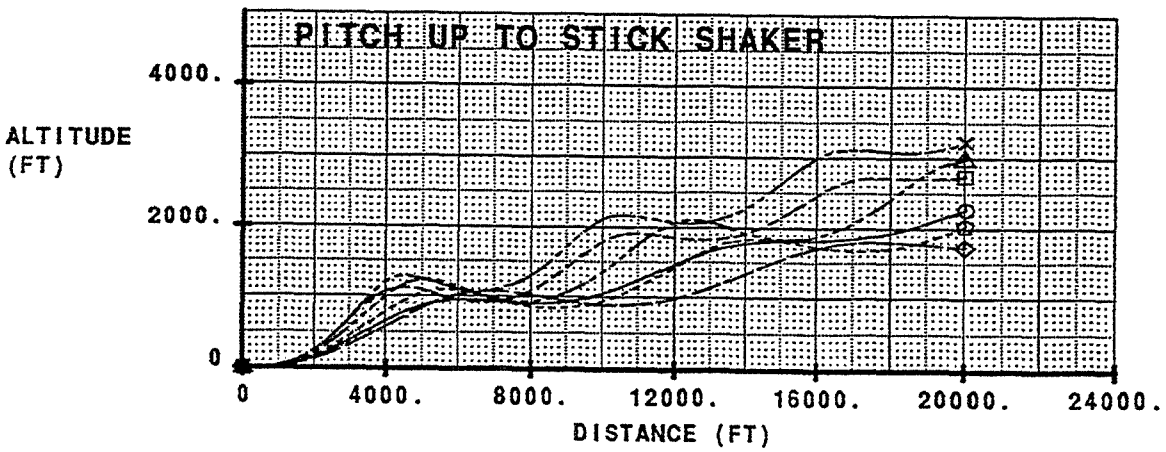
TAKEOFF FLAPS, SEA LEVEL

MAXIMUM TAKEOFF WEIGHT, LANDING GEAR UP, V2 SPEED, MAXIMUM THRUST APPLIED .5 SEC AFTER MANEUVER START, SPEED TRIM OPERATIVE WHERE APPLICABLE

727-200
737-300
747-400
757-200
767-300ER
777-200





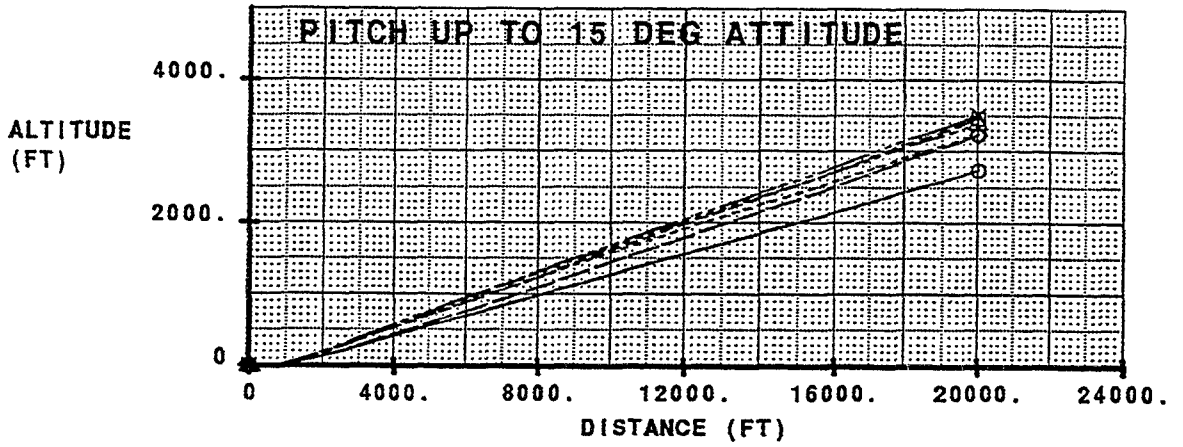


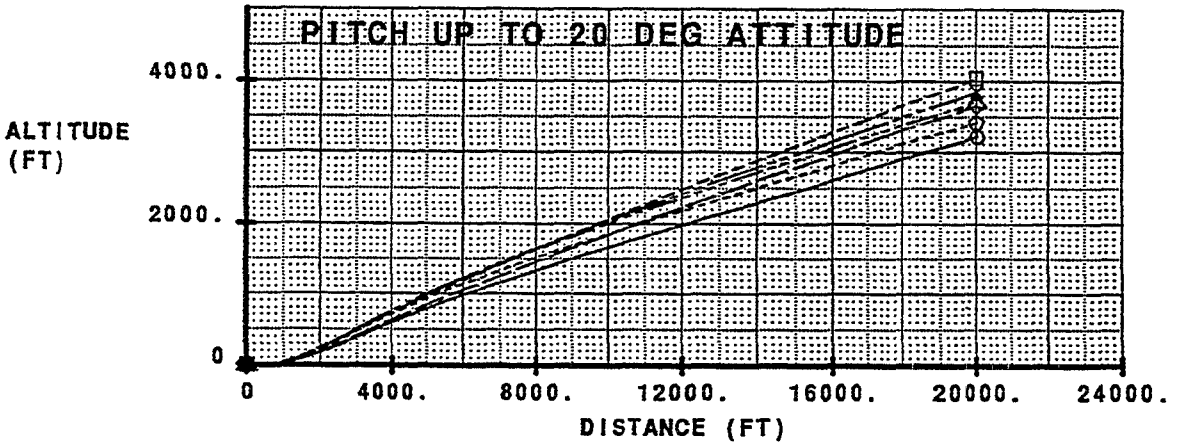
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Takeoff Flaps at Sea Level 3 Deg/Sec Pitch Rate	VARIOUS MODELS
CHECK						Figure 2
APR					THE BOEING COMPANY	PAGE
APR						

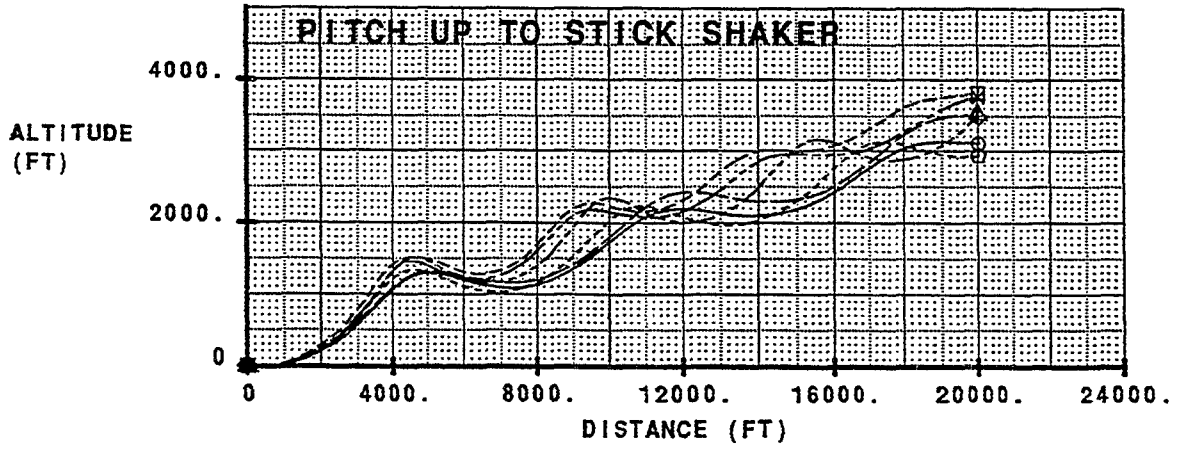
APPROACH FLAPS, SEA LEVEL

MAXIMUM LANDING WEIGHT, LANDING GEAR DOWN,
MANEUVERING SPEED, MAXIMUM THRUST APPLIED
.5 SEC AFTER MANEUVER START, SPEED TRIM
OPERATIVE WHERE APPLICABLE

- 727-200
- 737-300
- 747-400
- 757-200
- 767-300ER
- 777-200





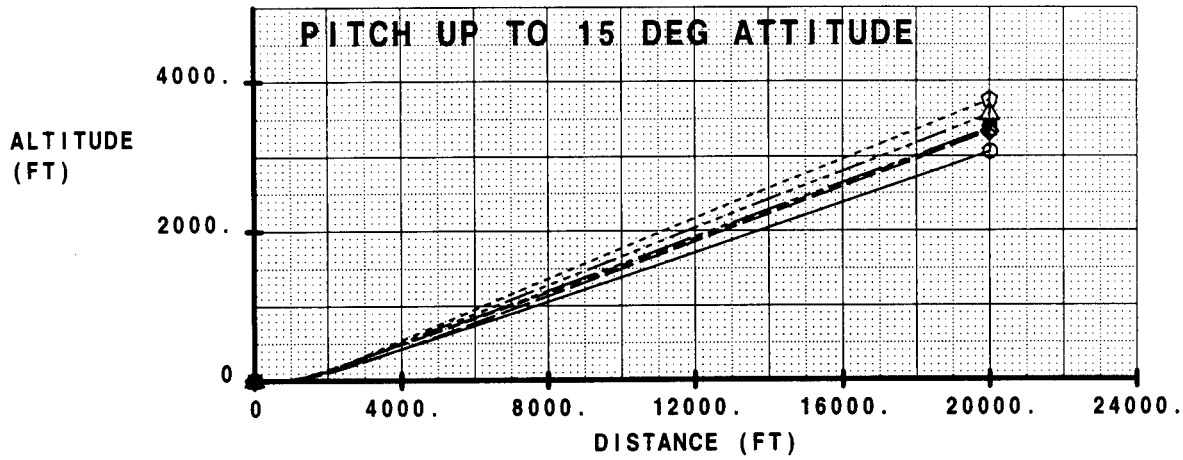


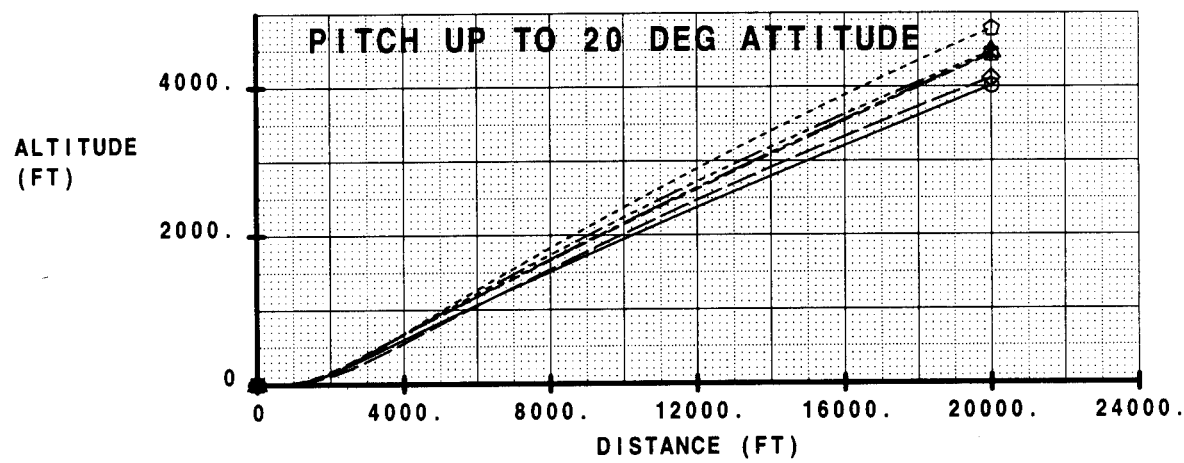
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Approach Flaps at Sea Level 3 Deg/Sec Pitch Rate	VARIOUS MODELS
CHECK						Figure 3
APR					THE BOEING COMPANY	PAGE
APR						

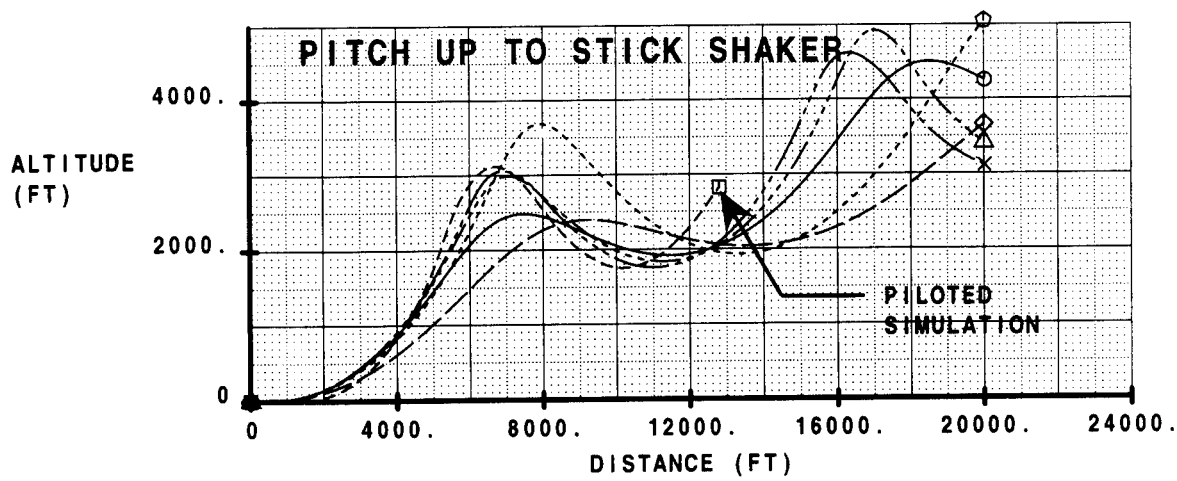
FLAPS UP, SEA LEVEL

MAXIMUM LANDING WEIGHT, LANDING GEAR UP, MANEUVERING SPEED, MAXIMUM THRUST APPLIED .5 SEC AFTER MANEUVER START, SPEED TRIM OPERATIVE WHERE APPLICABLE

727-200
737-300
747-400
757-200
767-300ER
777-200







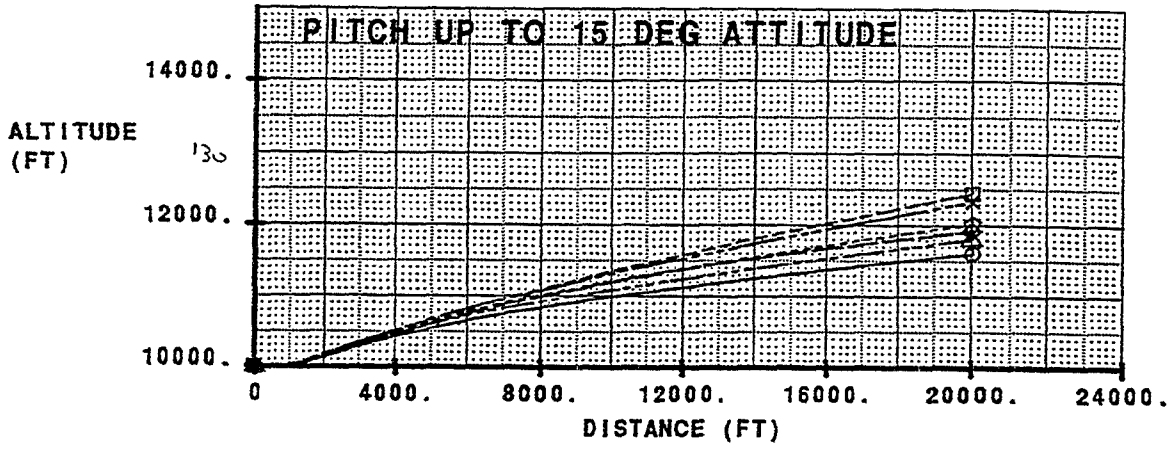
NOTE: MATH PILOT SIMULATION EXCEPT AS NOTED

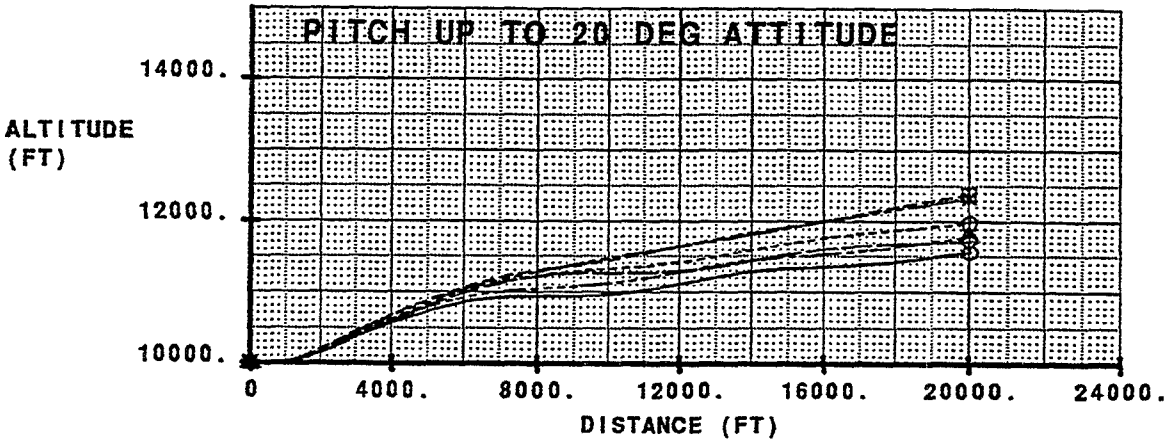
CALC		21APR97	REVISED	DATE	CFIT Escape Maneuver Study Flaps Up at Sea Level 3 Deg/Sec Pitch Rate	VARIOUS MODELS
CHECK						Figure 4
APR					THE BOEING COMPANY	PAGE
APR						

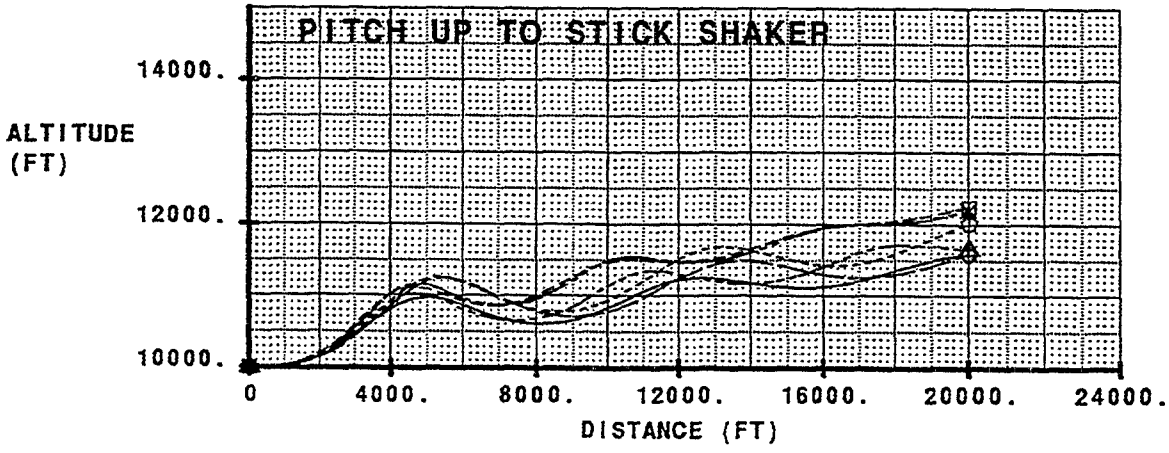
LANDING FLAPS, 10000 FT

MAXIMUM LANDING WEIGHT, LANDING GEAR DOWN, VREF +5 KNOTS, MAXIMUM THRUST APPLIED .5 SEC AFTER MANEUVER START, SPEED TRIM OPERATIVE WHERE APPLICABLE

- 727-200
- 737-300
- 747-400
- 757-200
- 767-300ER
- 777-200





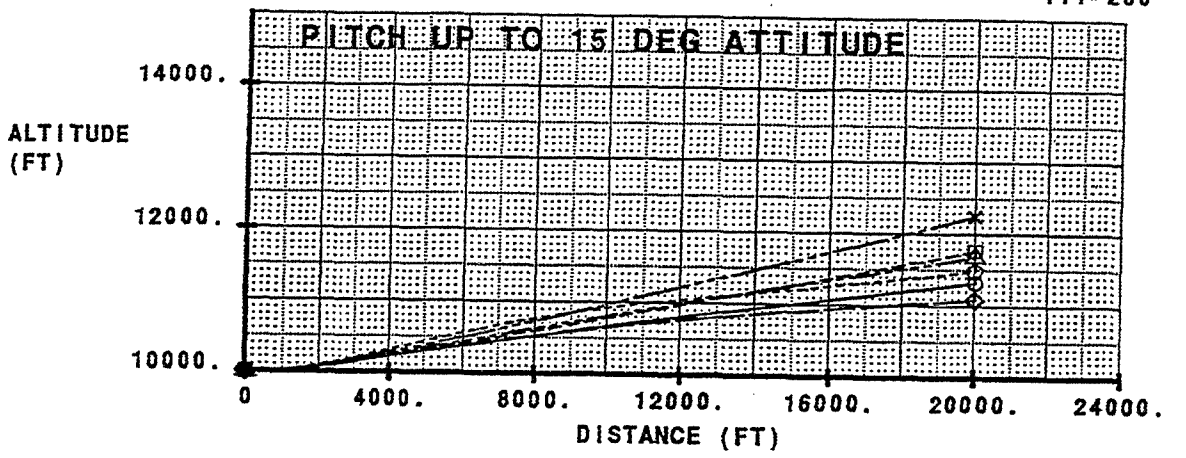


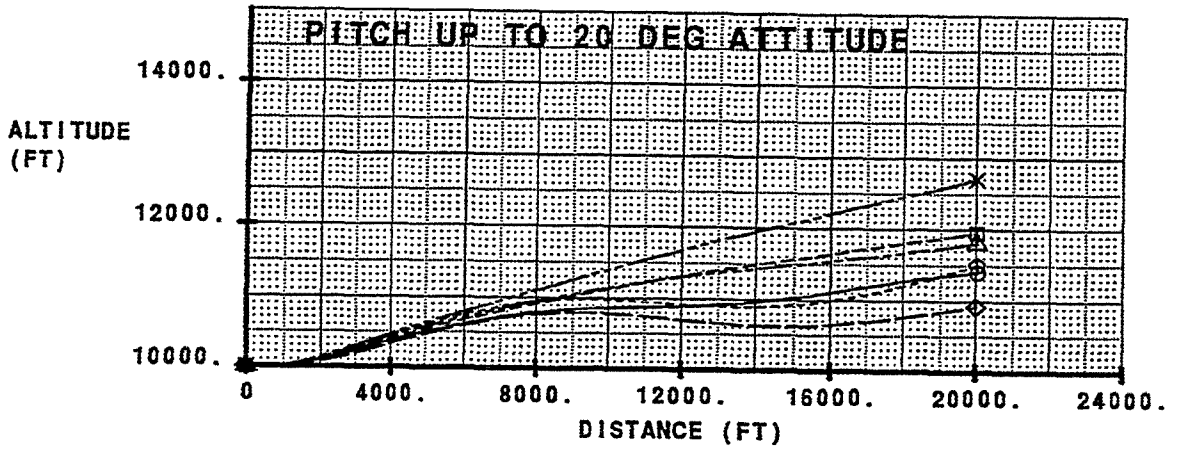
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Landing Flaps at 10000 ft 3 Deg/Sec Pitch Rate	VARIOUS MODELS
CHECK						Figure 5
APR					THE BOEING COMPANY	PAGE
APR						

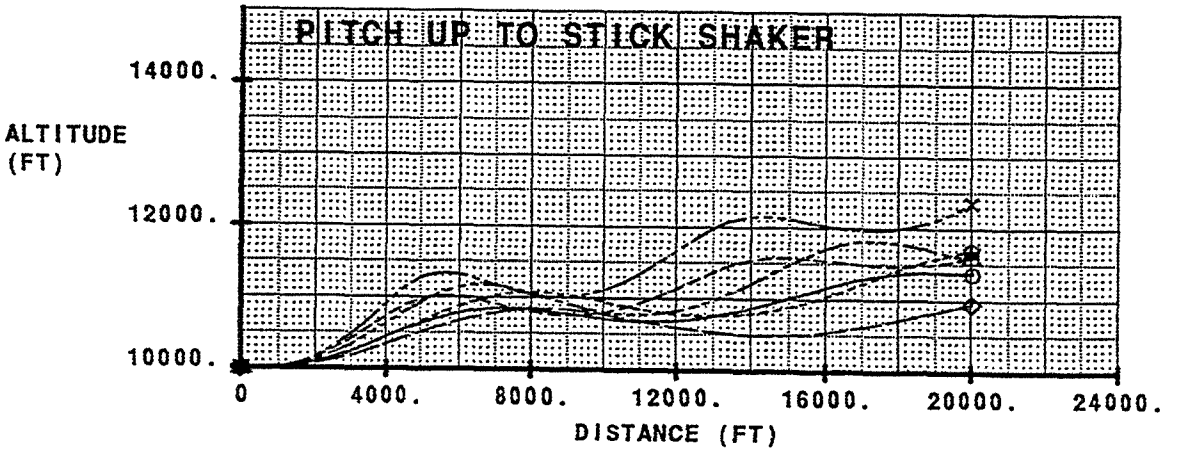
TAKEOFF FLAPS, 10000 FT

MAXIMUM TAKEOFF WEIGHT, LANDING GEAR UP, V2 SPEED, MAXIMUM THRUST APPLIED .5 SEC AFTER MANEUVER START, SPEED TRIM OPERATIVE WHERE APPLICABLE

727-200
737-300
747-400
757-200
767-300ER
777-200







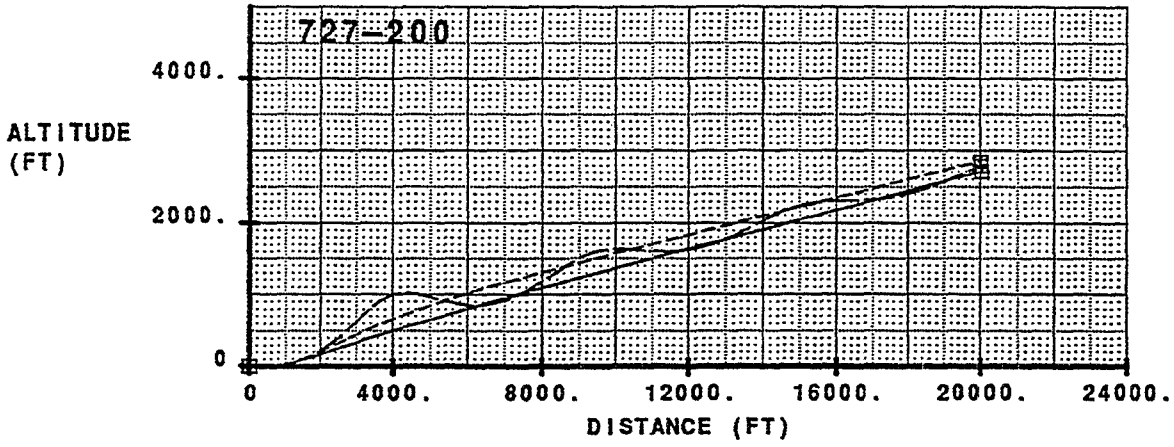
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Takeoff Flaps at 10000 ft 3 Deg/Sec Pitch Rate	VARIOUS MODELS
CHECK						Figure 6
APR					THE BOEING COMPANY	PAGE
APR						

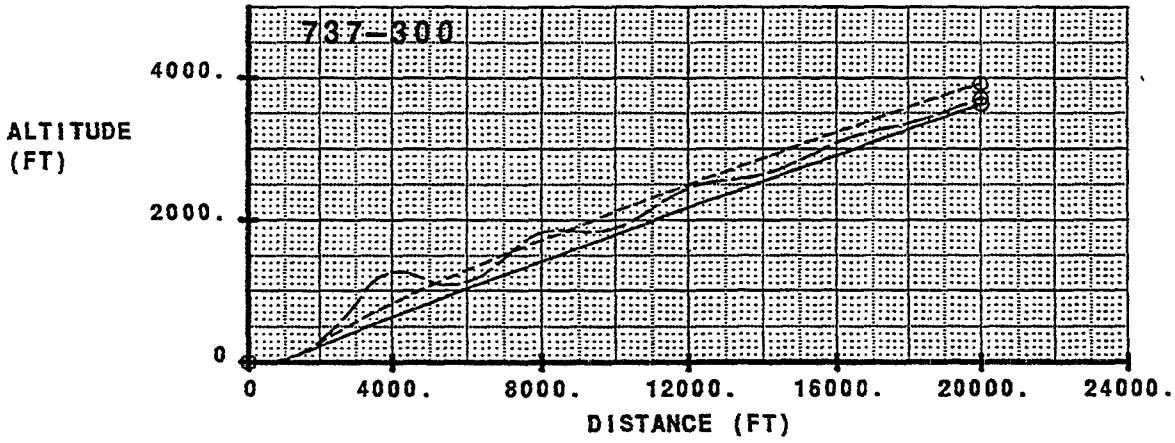
LANDING FLAPS, SEA LEVEL

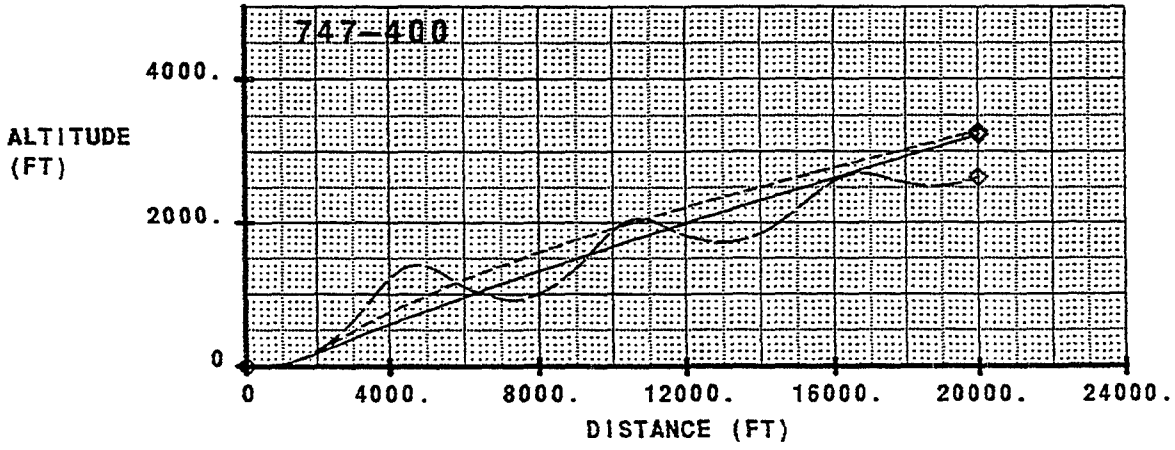
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - 20 DEG
——— STICK SHAKER







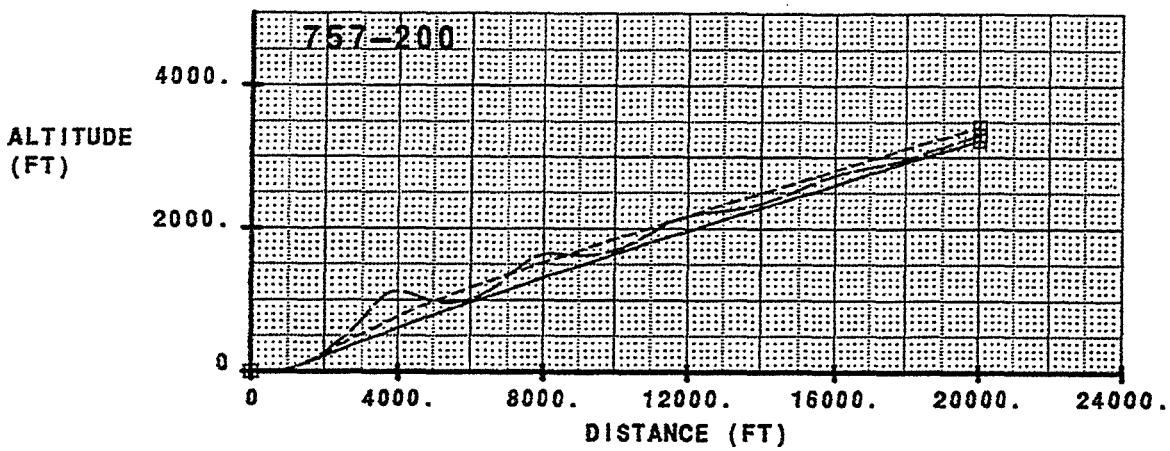
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Landing Flaps at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	727,737,747
CHECK						Figure 7A
APR						PAGE
APR					THE BOEING COMPANY	

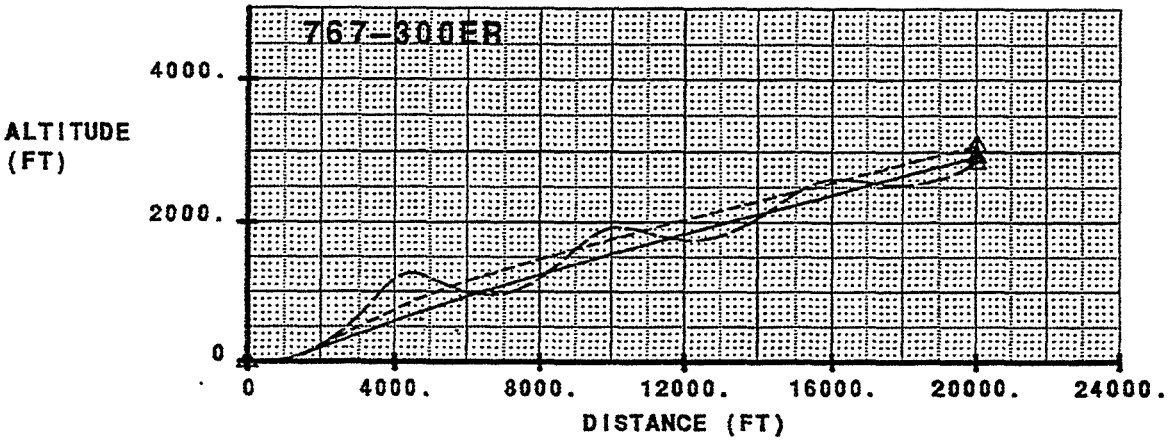
LANDING FLAPS, SEA LEVEL

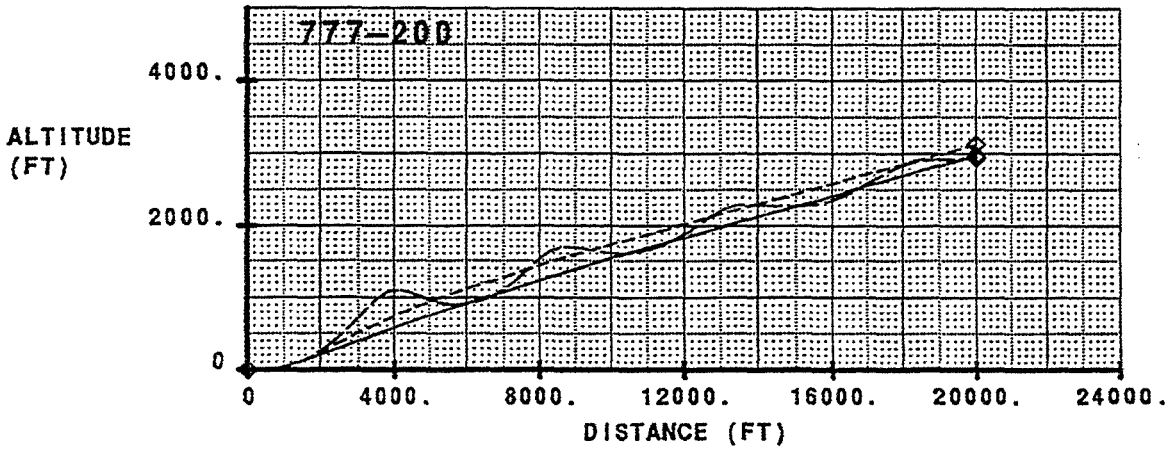
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——————— 15 DEG
- - - - - - - - - 20 DEG
—·—·—·— STICK SHAKER







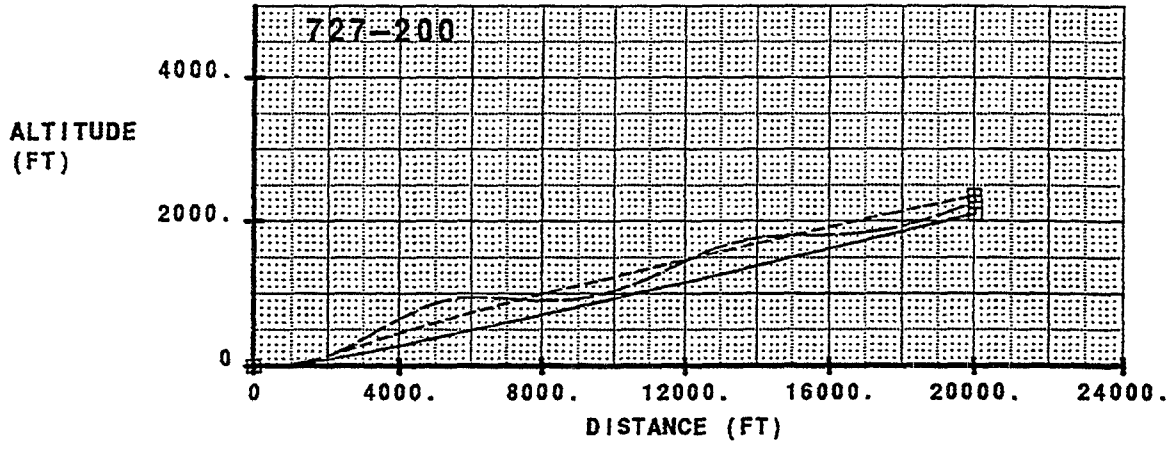
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Landing Flaps at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	757,767,777
CHECK						Figure 7B
APR						
APR					THE BOEING COMPANY	PAGE

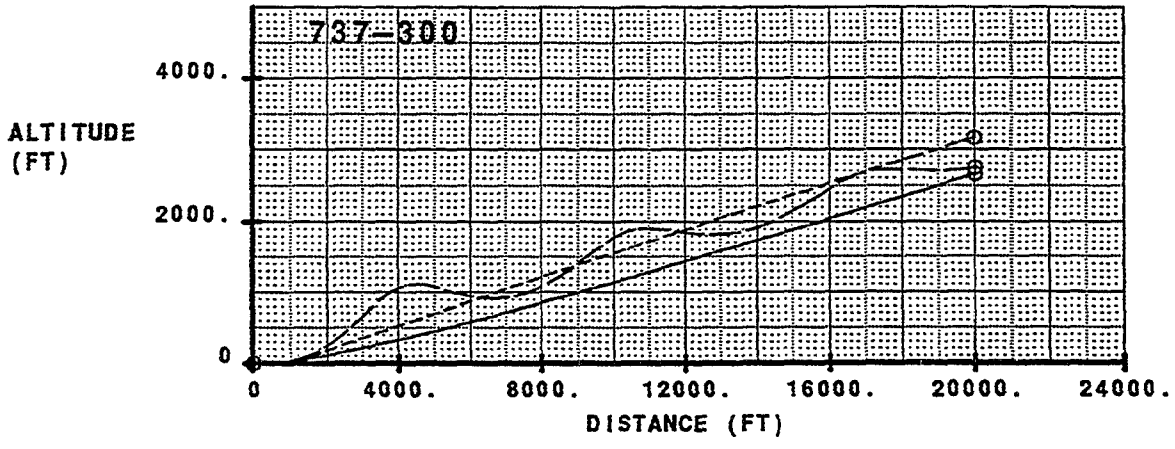
TAKEOFF FLAPS, SEA LEVEL

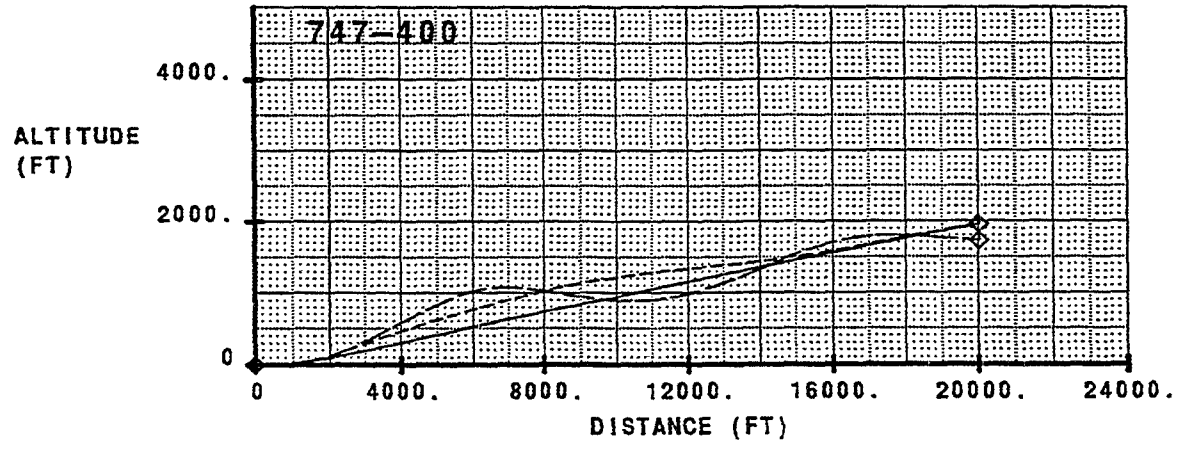
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - 20 DEG
——— STICK SHAKER







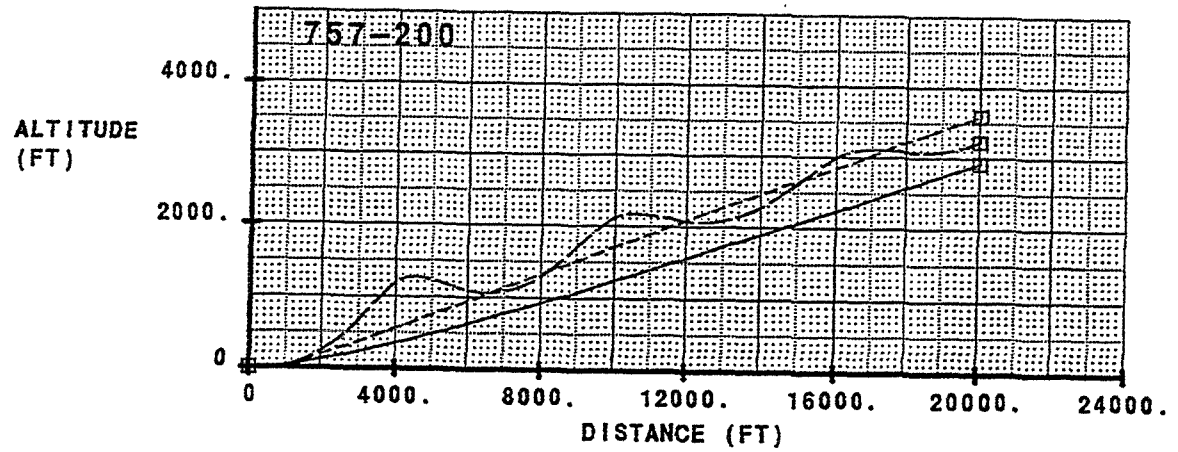
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Takeoff Flaps at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	727,737,747
CHECK						Figure 8A
APR						
APR					THE BOEING COMPANY	PAGE

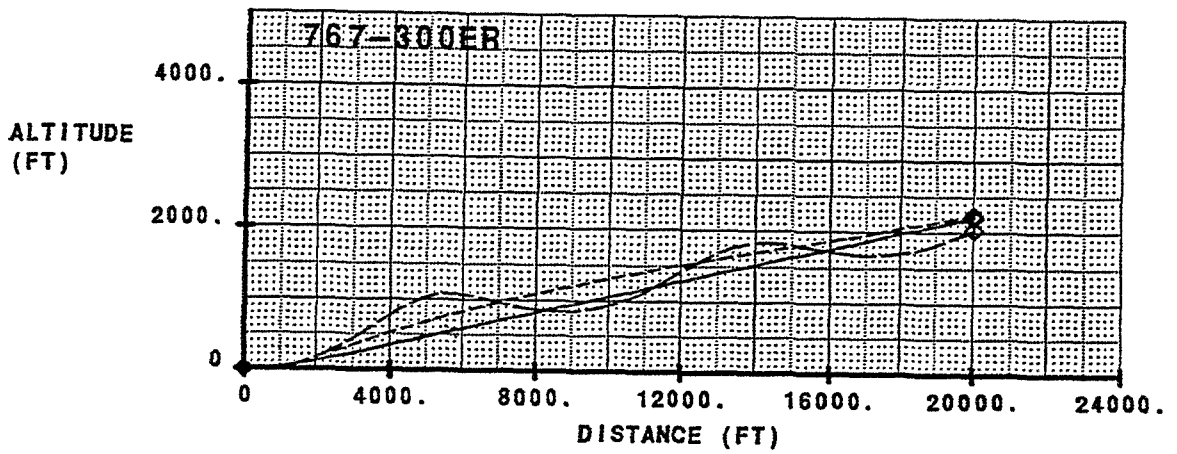
TAKEOFF FLAPS, SEA LEVEL

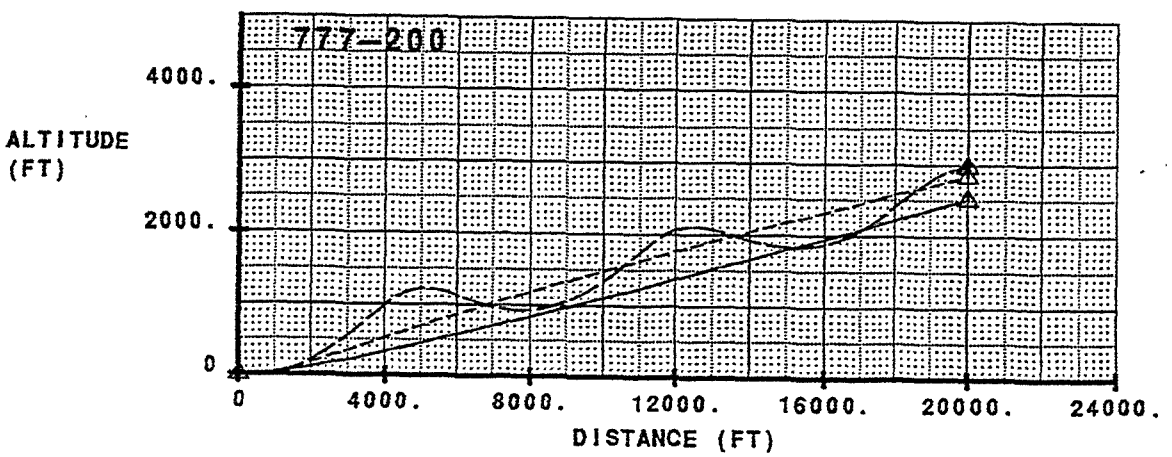
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - 20 DEG
—·—·— STICK SHAKER







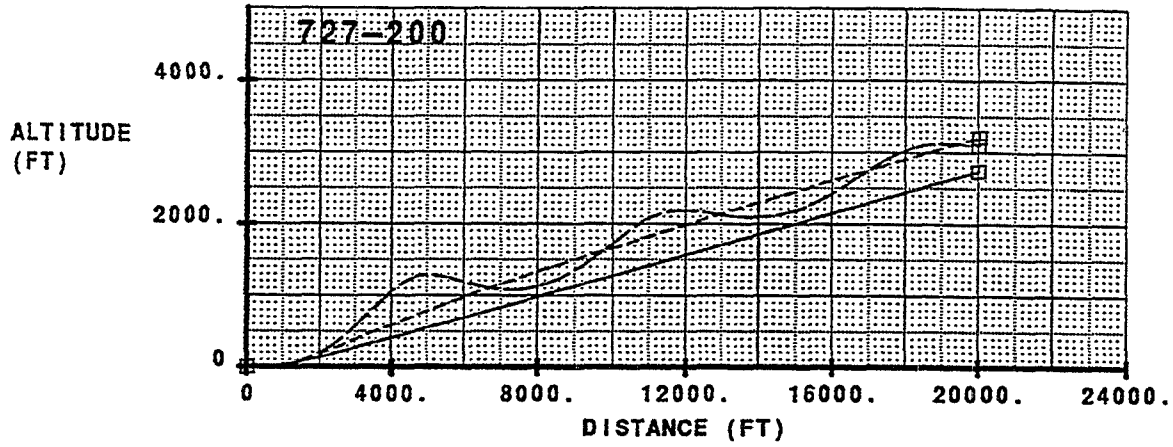
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Takeoff Flaps at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	757,767,777
CHECK						Figure 8B
APR						
APR					THE BOEING COMPANY	PAGE

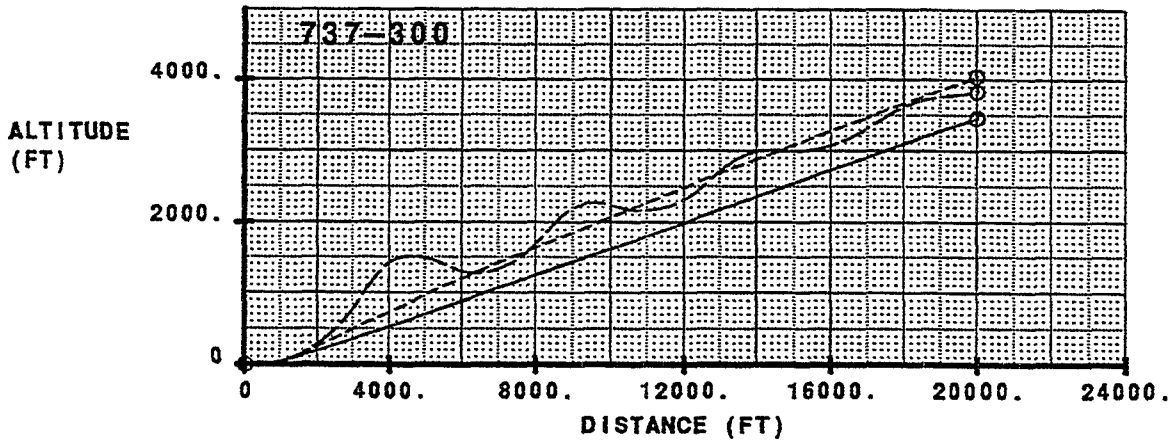
APPROACH FLAPS, SEA LEVEL

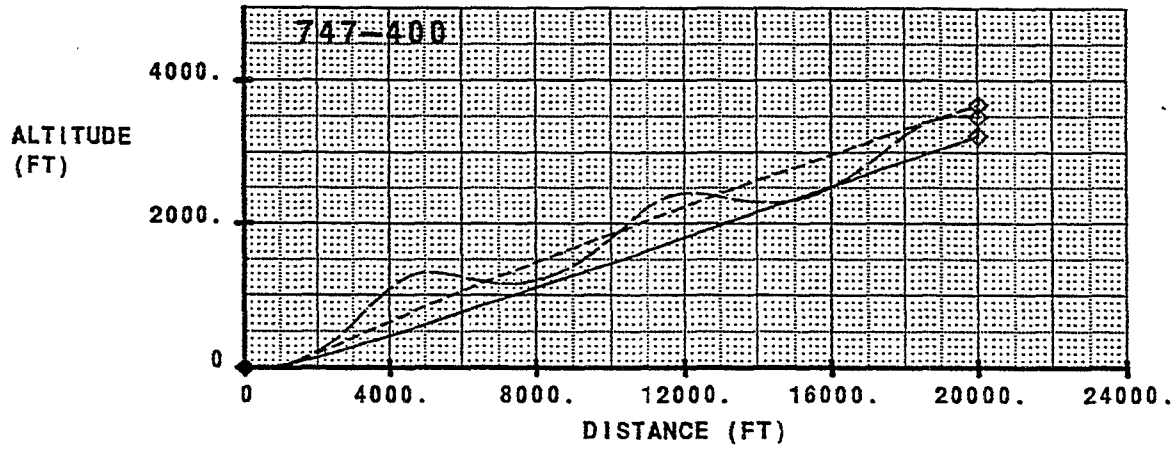
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
15 DEG
20 DEG
STICK SHAKER







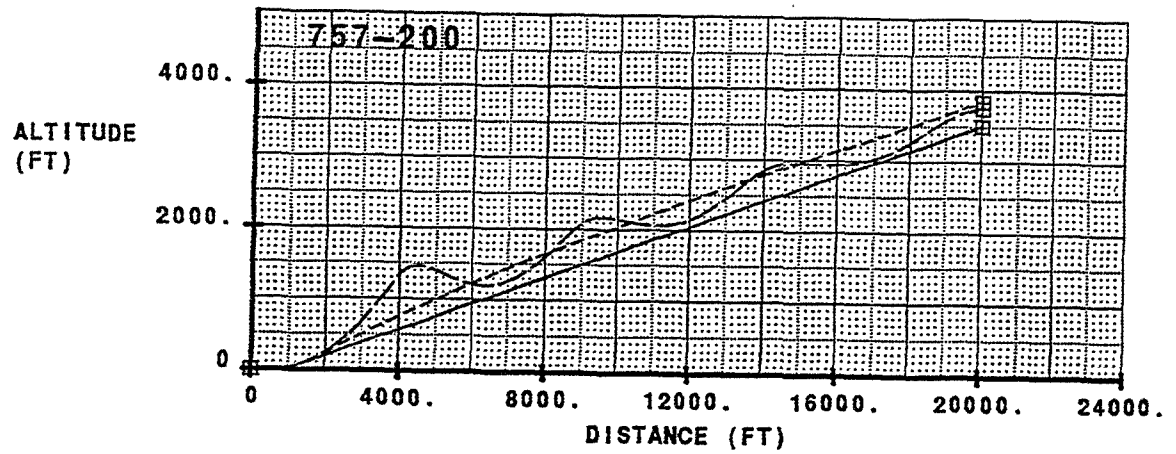
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Approach Flaps at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	727,737,747
CHECK						Figure 9A
APR						
APR					THE BOEING COMPANY	PAGE

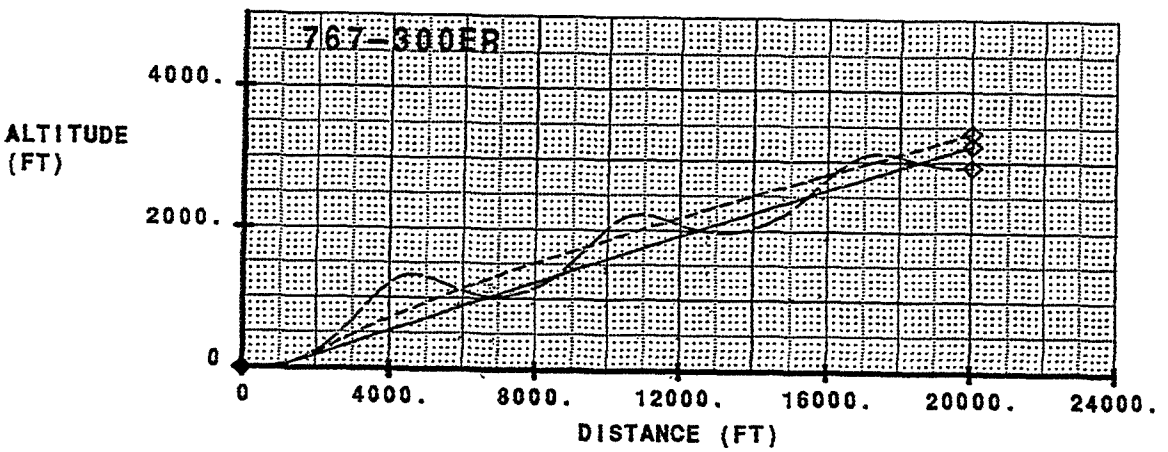
APPROACH FLAPS, SEA LEVEL

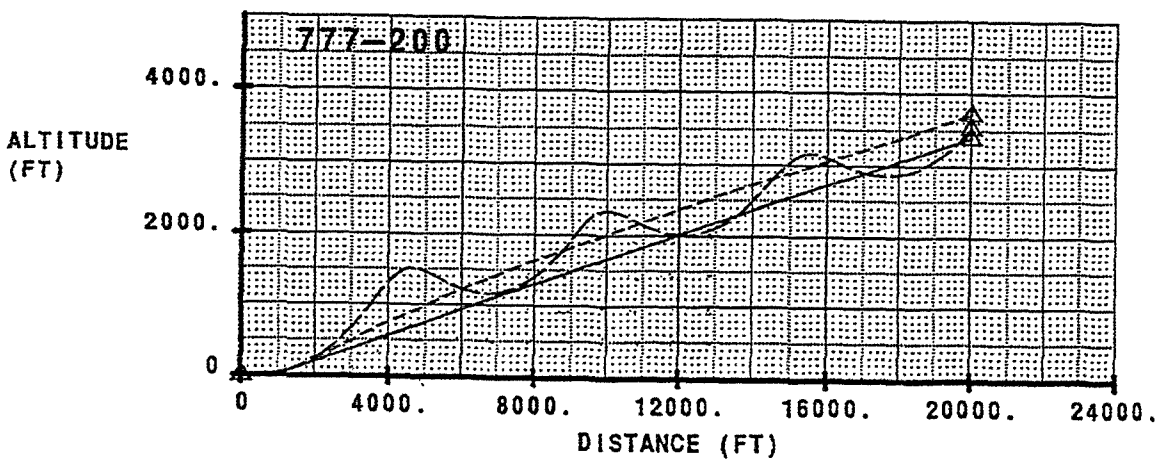
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - - 20 DEG
—·—·— STICK SHAKER







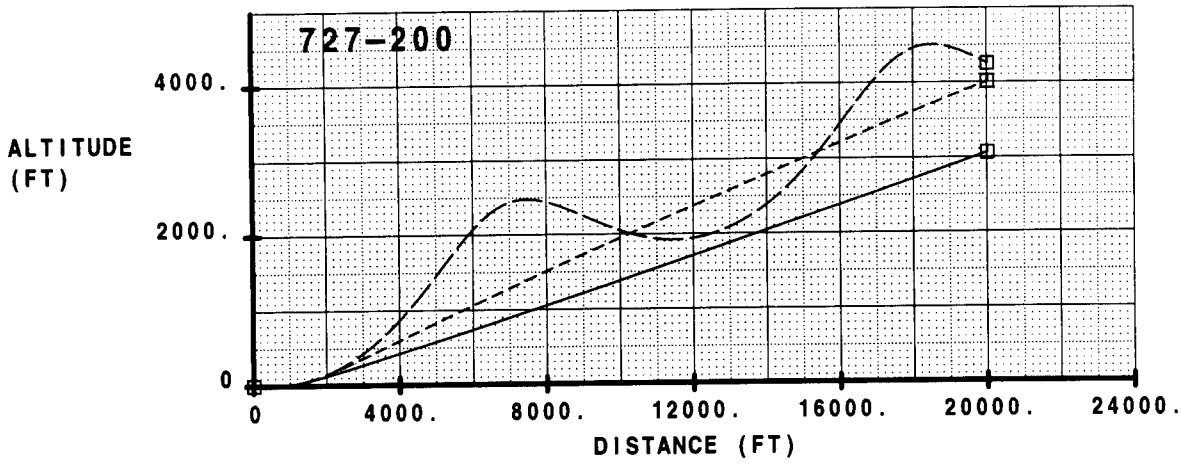
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Approach Flaps at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	757,767,777
CHECK						Figure 9B
APR					THE BOEING COMPANY	PAGE
APR						

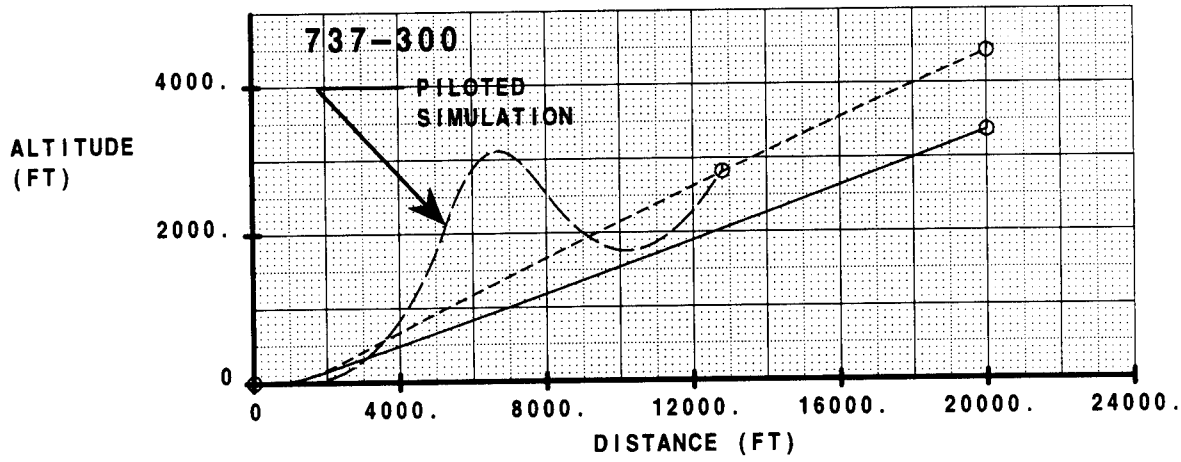
FLAPS UP, SEA LEVEL

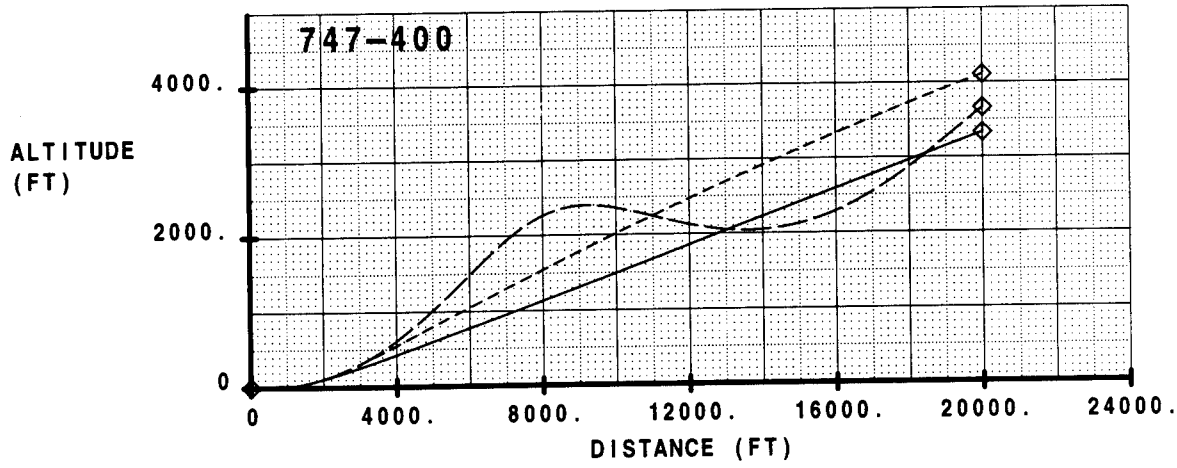
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - - 20 DEG
— — — STICK SHAKER







NOTE: MATH PILOT SIMULATION EXCEPT AS NOTED

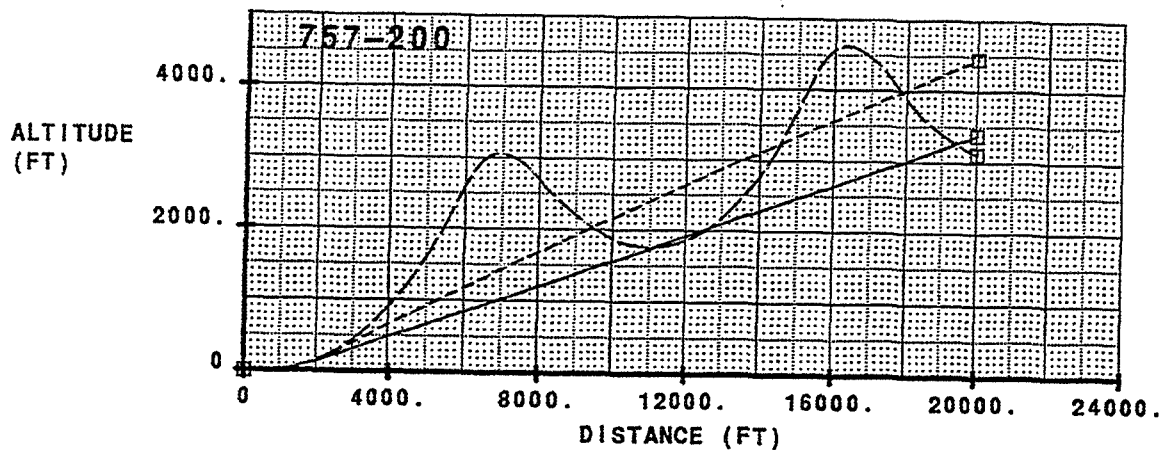
CALC		21APR97	REVISED	DATE	CFIT Escape Maneuver Study Flaps Up at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	727,737,747
CHECK						Figure 10A
APR					THE BOEING COMPANY	PAGE
APR						

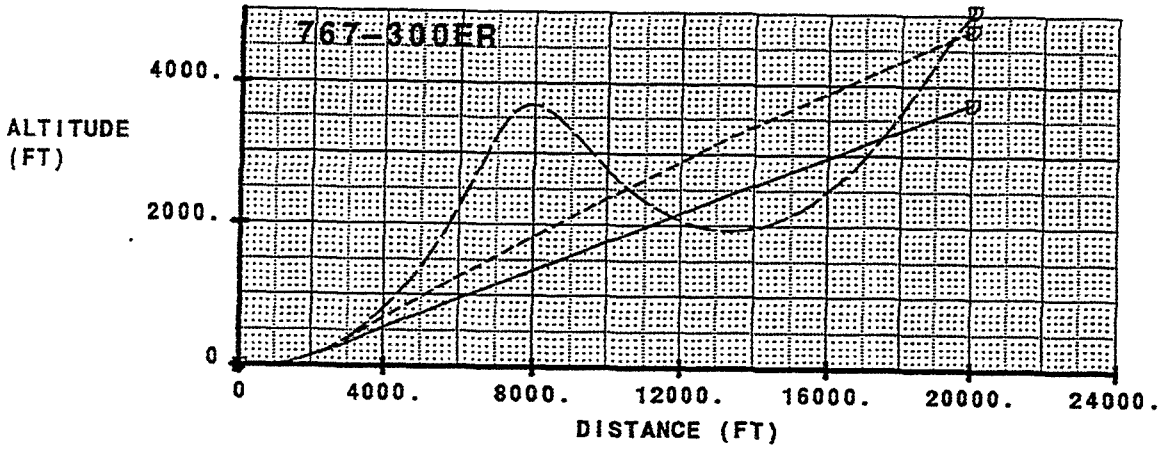
FLAPS UP, SEA LEVEL

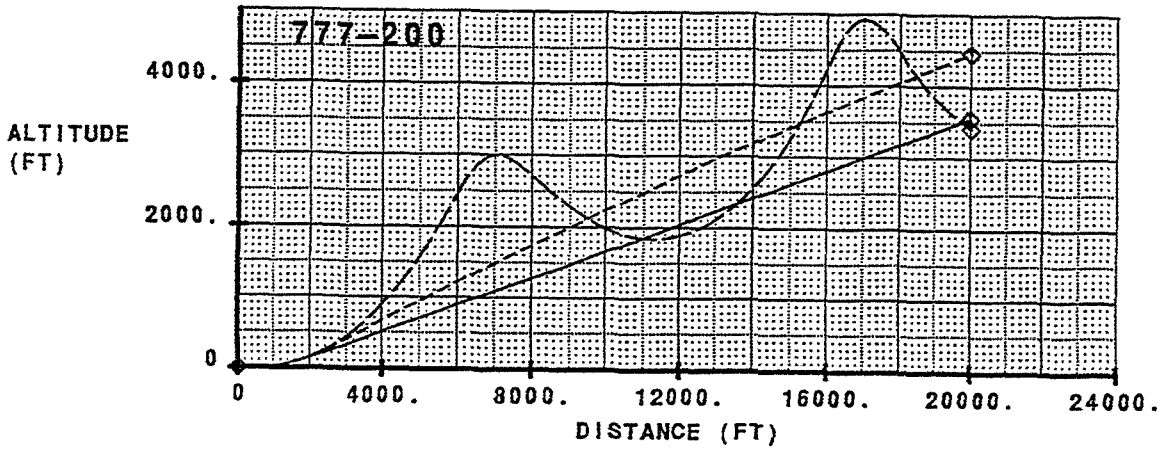
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - 20 DEG
—·—·— STICK SHAKER







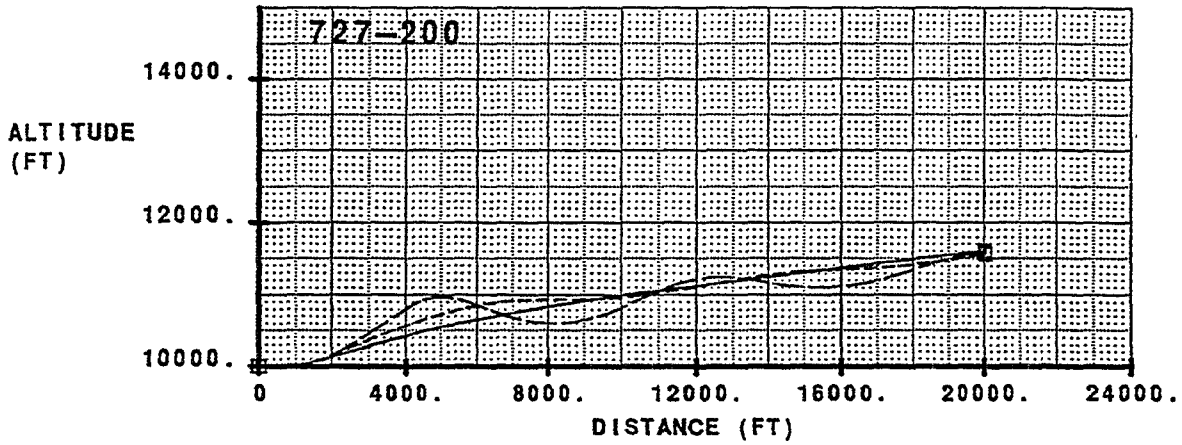
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Flaps Up at Sea Level Pitch Up to 15 Deg, 20 Deg & Shaker	757,767,777
CHECK						Figure 10B
APR					THE BOEING COMPANY	PAGE
APR						

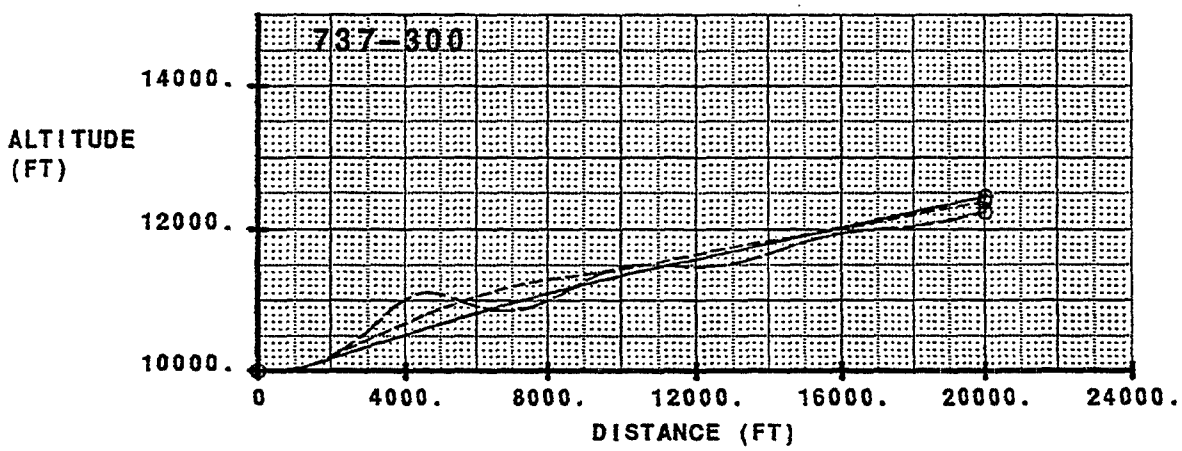
LANDING FLAPS, 10000 FT

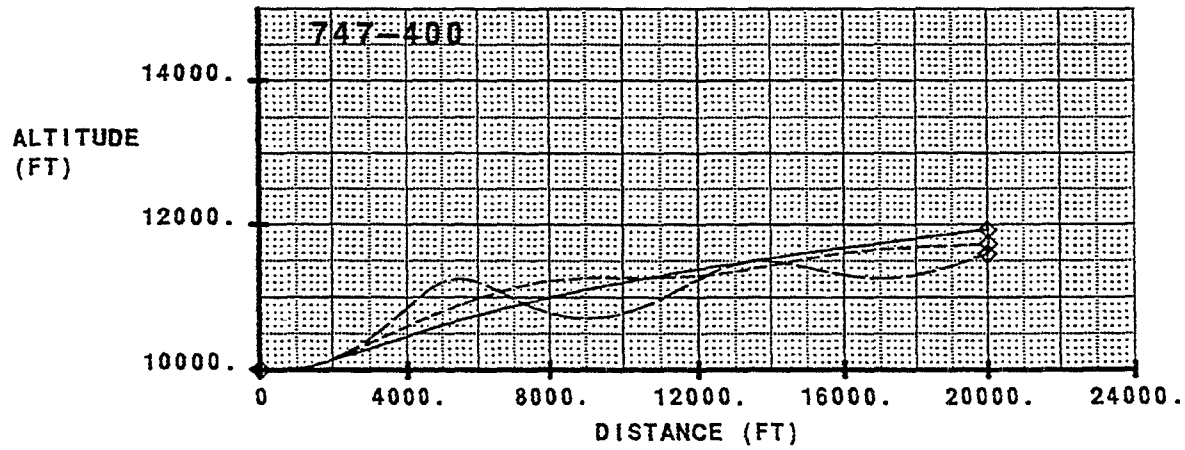
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - 20 DEG
—·—·— STICK SHAKER







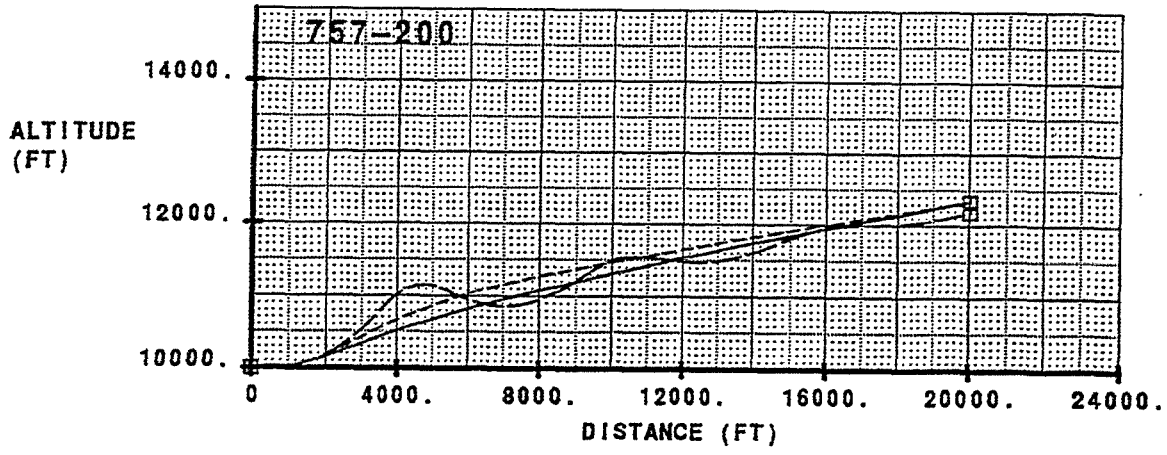
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Landing Flaps at 10000 ft Pitch Up to 15 Deg, 20 Deg & Shaker	727,737,747
CHECK						Figure 11A
APR						
APR					THE BOEING COMPANY	PAGE

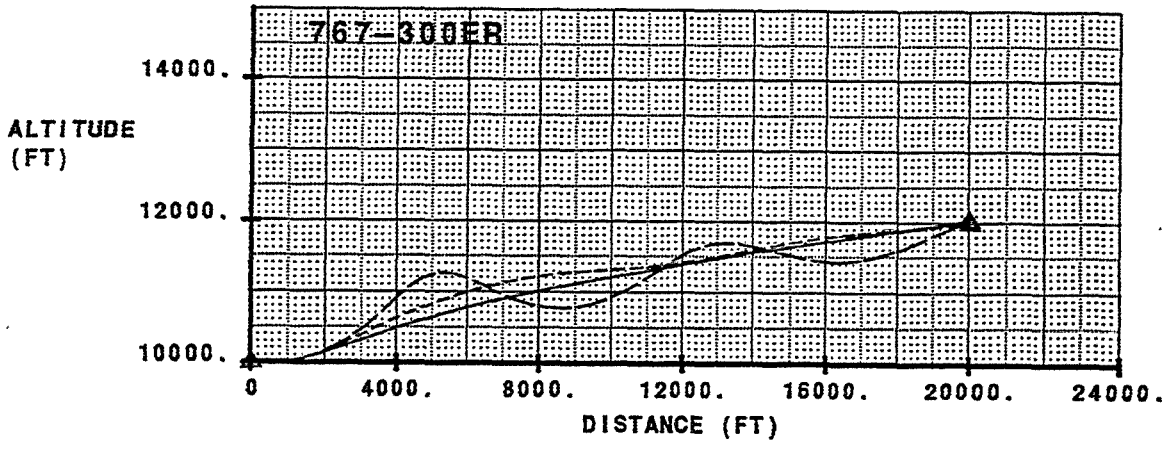
LANDING FLAPS, 10000 FT

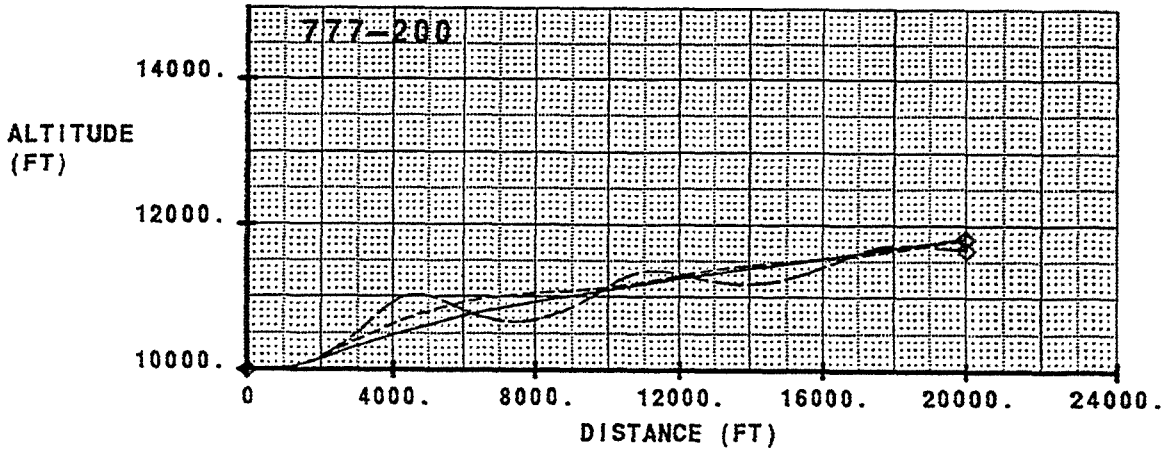
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - - 20 DEG
—·—·— STICK SHAKER







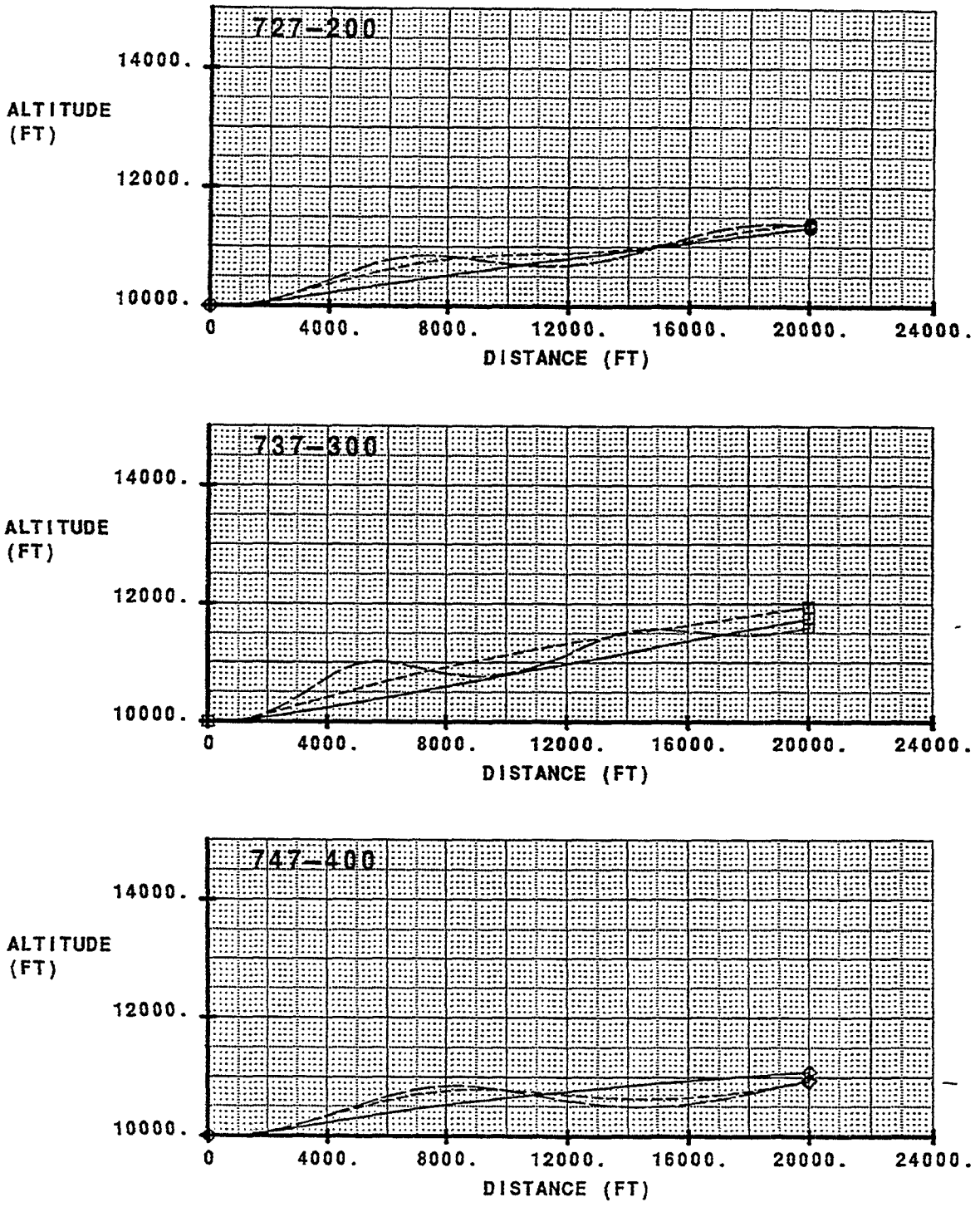
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Landing Flaps at 10000 ft Pitch Up to 15 Deg, 20 Deg & Shaker	757,767,777
CHECK						Figure 11B
APR					THE BOEING COMPANY	PAGE
APR						

TAKEOFF FLAPS, 10000 FT

PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
- 15 DEG
- 20 DEG
- STICK SHAKER



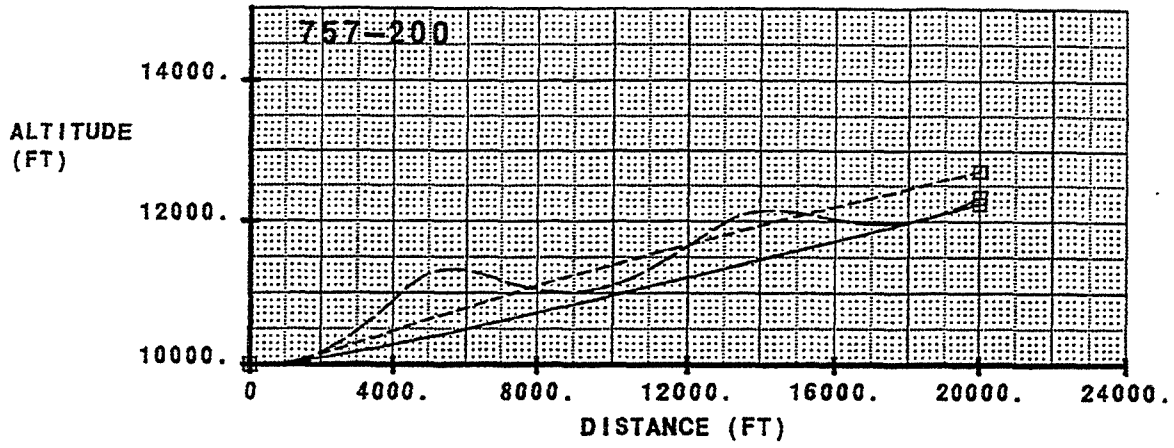
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Takeoff Flaps at 10000 ft Pitch Up to 15 Deg, 20 Deg & Shaker	727,737,747
CHECK						Figure 12A
APR					THE BOEING COMPANY	PAGE
APR						

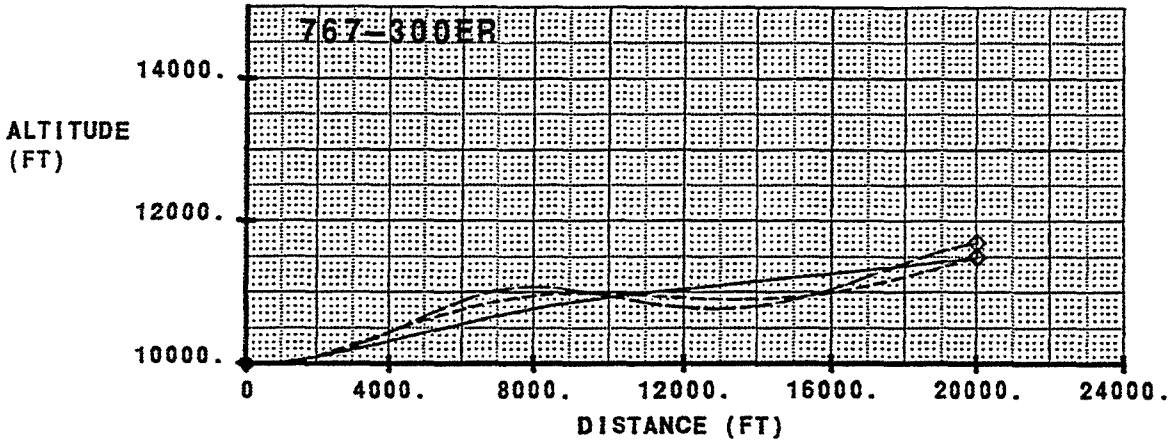
TAKEOFF FLAPS, 10000 FT

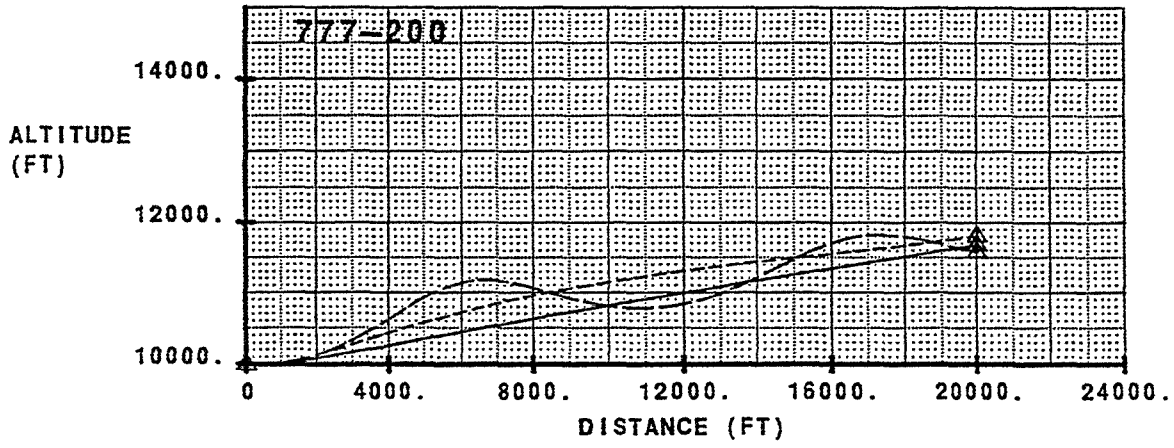
PITCH UP TO 15 DEG VS 20 VS SHAKER

3 DEG/SEC PITCH RATE

PITCH UP TO:
——— 15 DEG
- - - 20 DEG
—·—·— STICK SHAKER



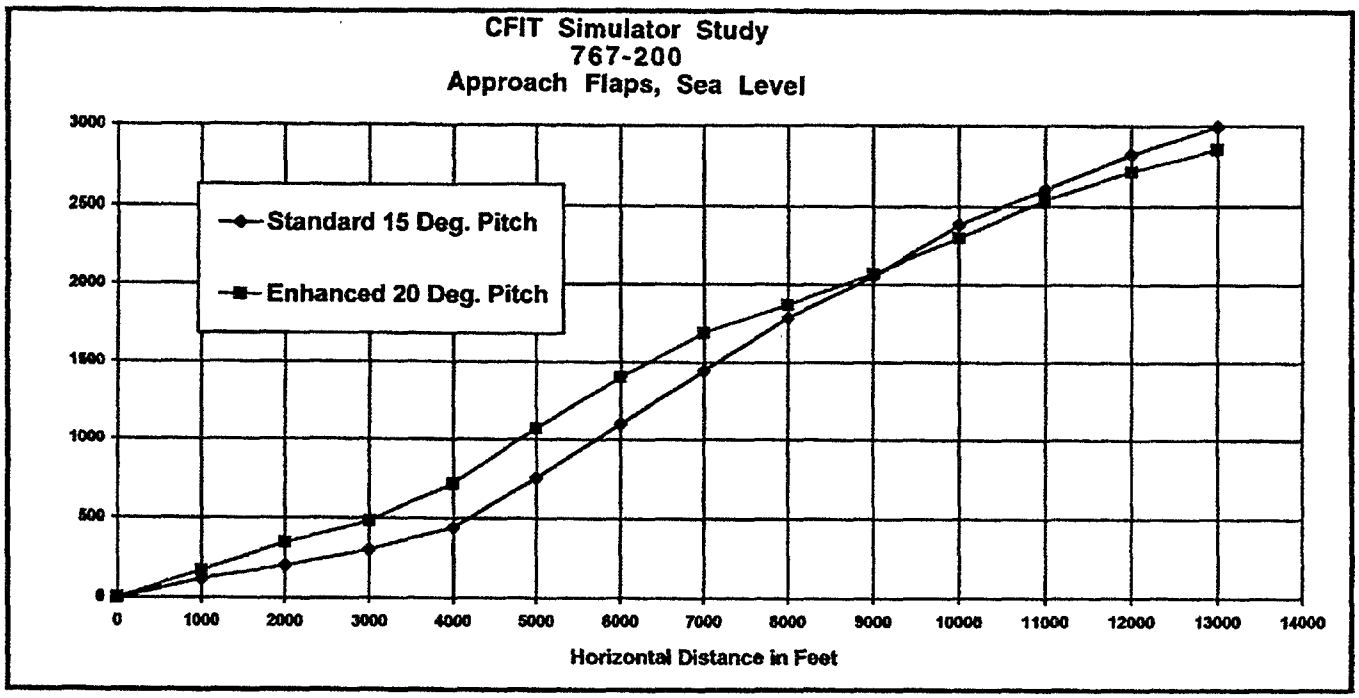


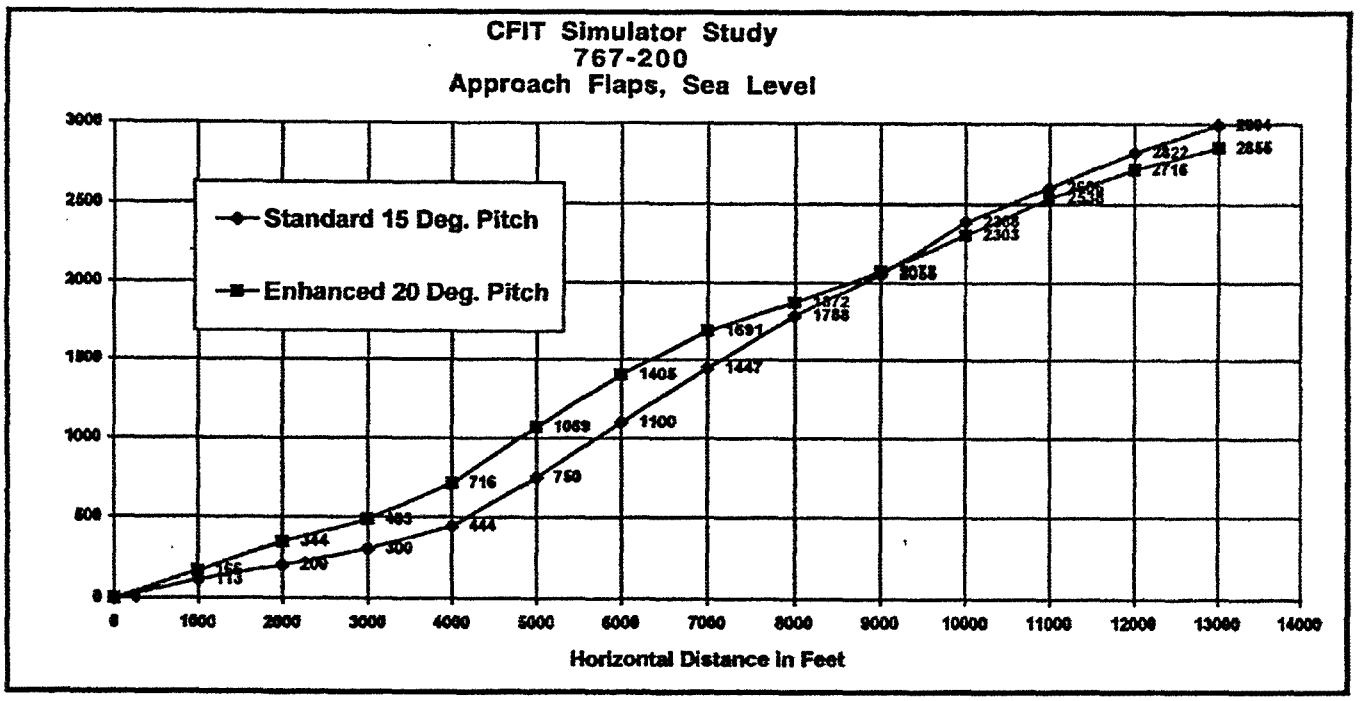


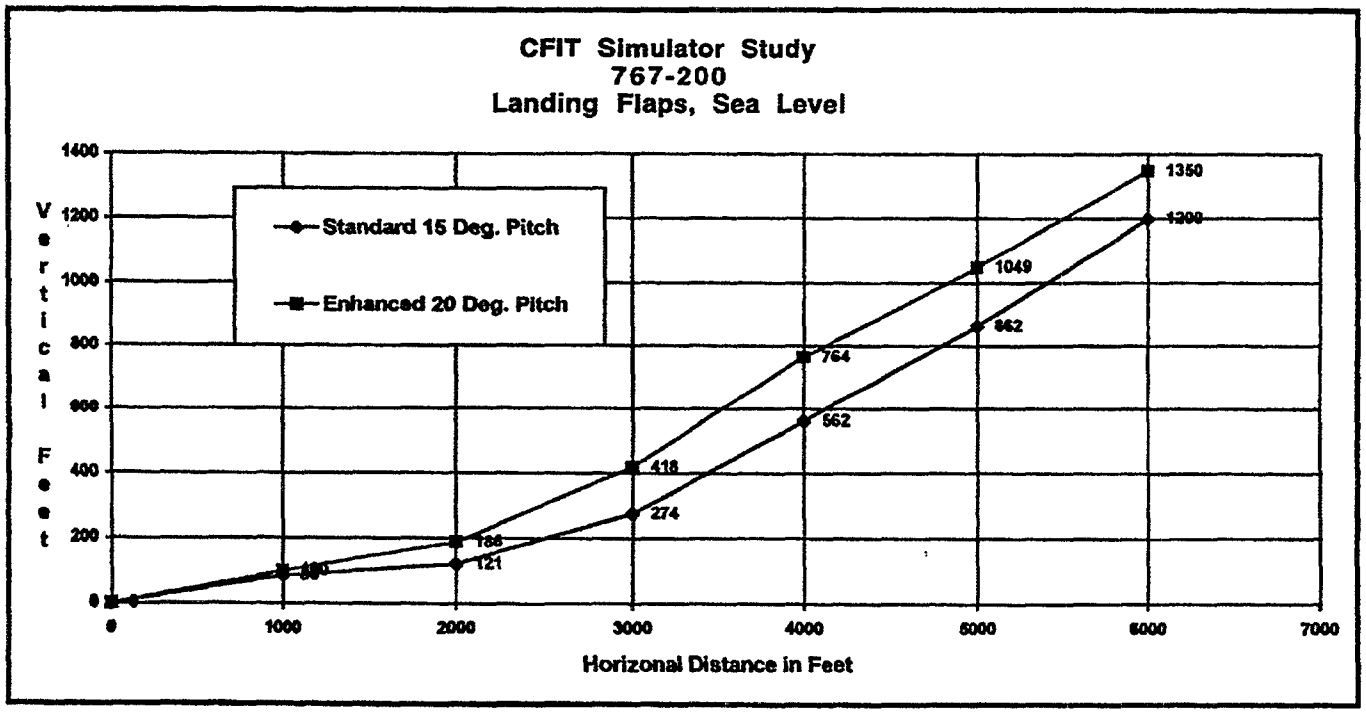
CALC		19MAY95	REVISED	DATE	CFIT Escape Maneuver Study Takeoff Flaps at 10000 ft Pitch Up to 15 Deg, 20 Deg & Shaker	757,767,777
CHECK						Figure 12B
APR					THE BOEING COMPANY	PAGE
APR						

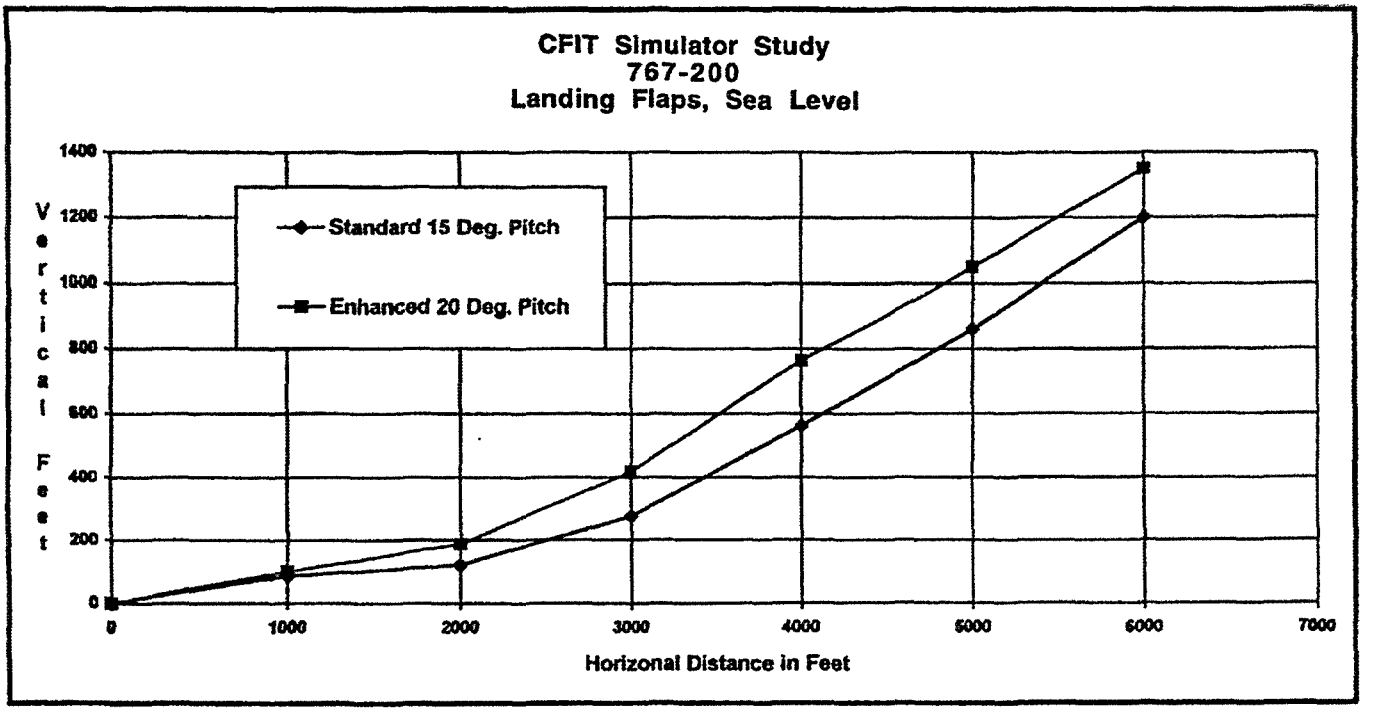
Boeing Flight Simulator Pilot Study

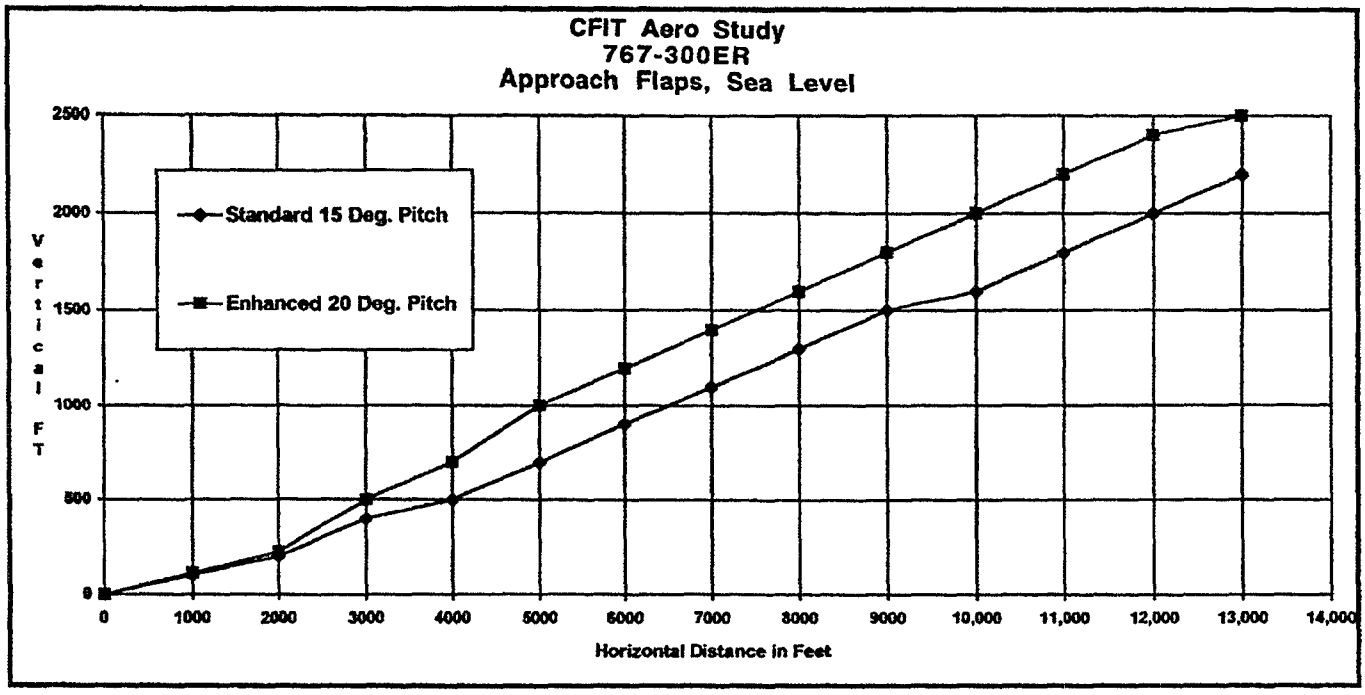
The flight simulator pilot study was conducted in a Boeing 767-200 airplane simulator to evaluate ground proximity warning escape maneuvers. This simulator is indicative of the general performance of the Boeing airplanes, and data will vary little from other Boeing models. The initial conditions for the study are typical of an airplane encountering rapidly rising terrain. Altitude (ft) is graphed on the vertical axis and distance traveled (ft) is graphed on the horizontal axis.

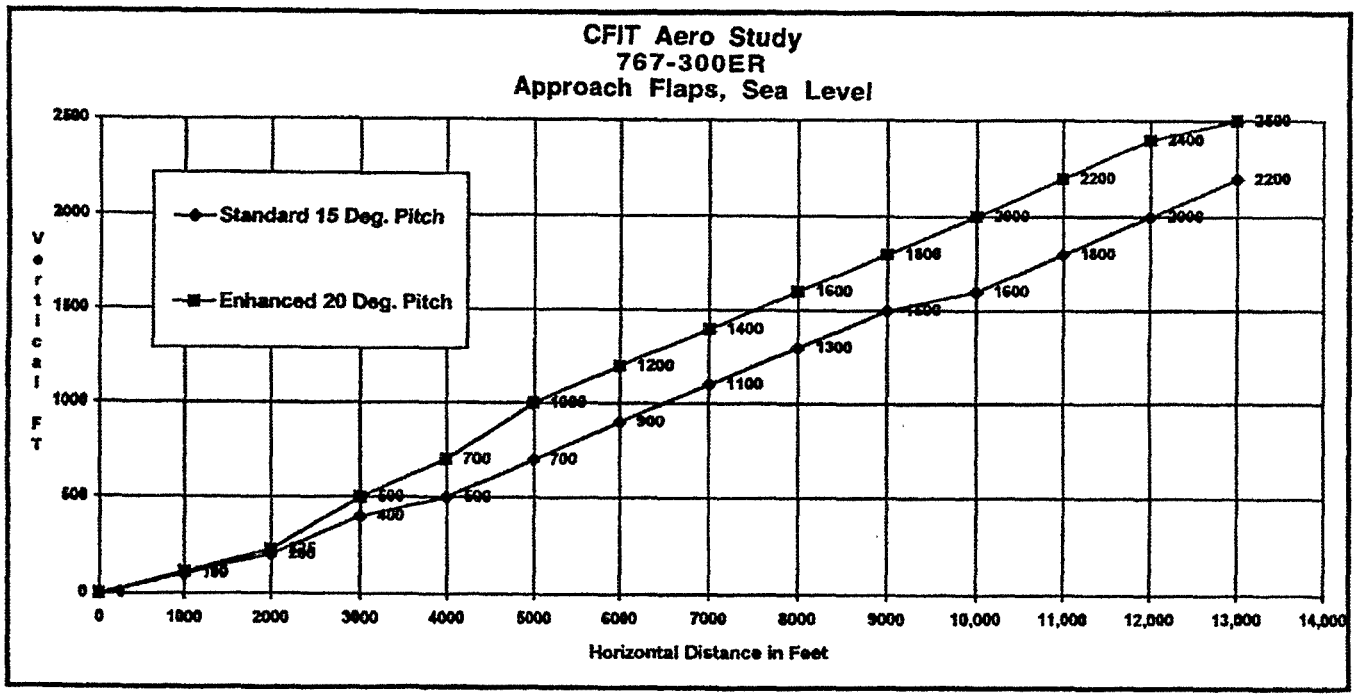

CFIT Simulator Study
767-200
Approach Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
3000
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
Horizontal Distance in Feet

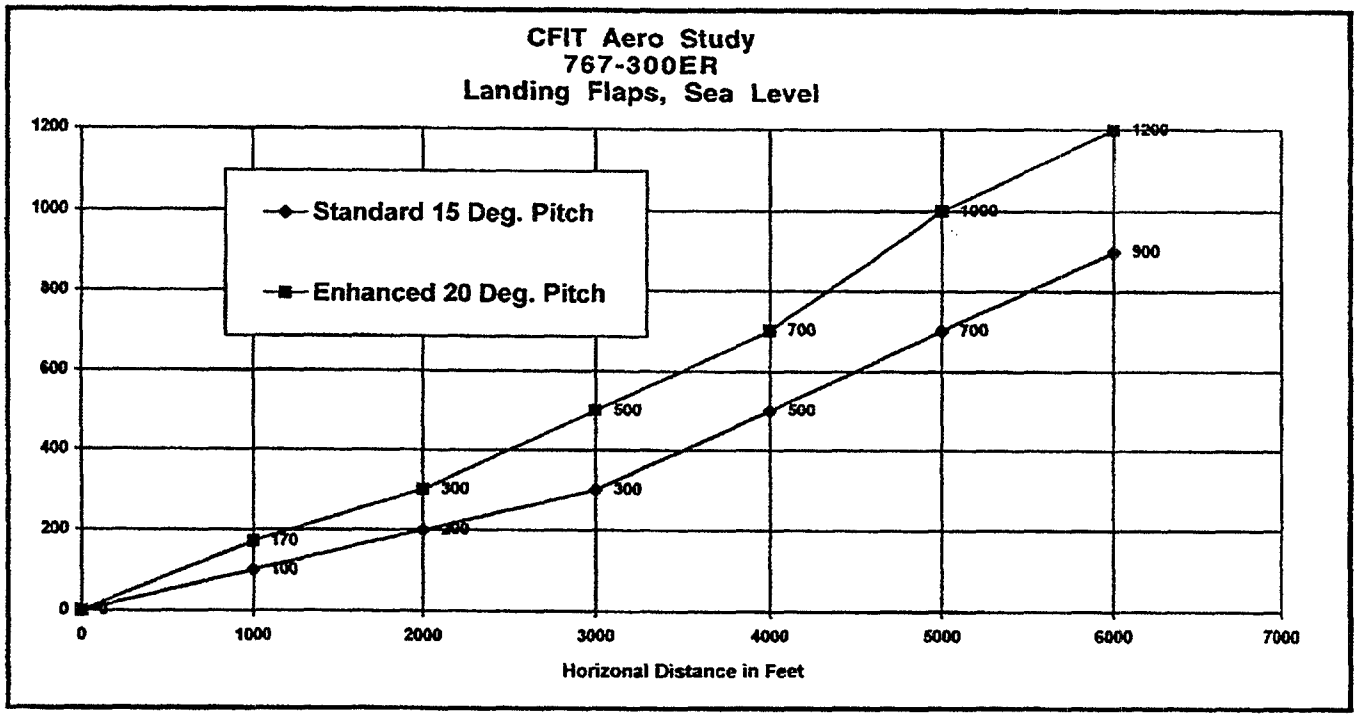
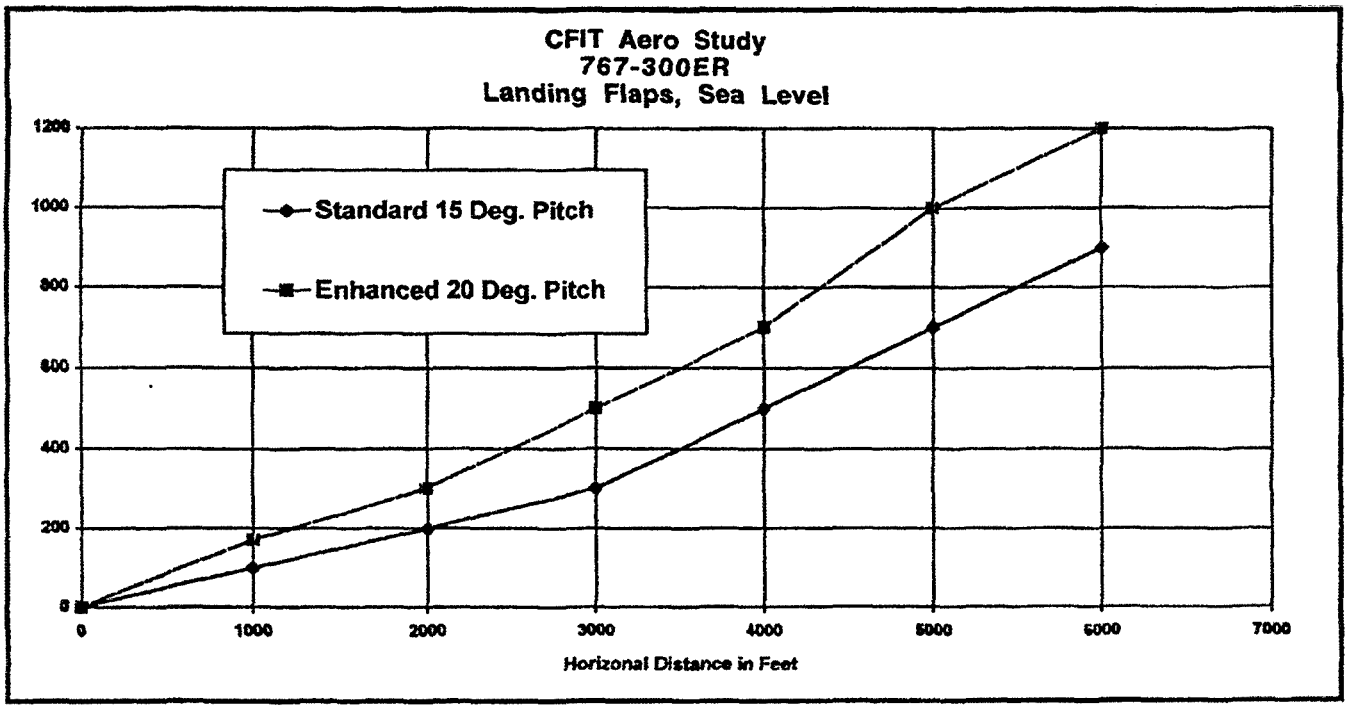

CFIT Simulator Study
767-200
Approach Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
Horizontal Distance in Feet
0
500
1000
1500
2000
2500
3000
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
344
716
1069
1405
1691
2303
2716
2855
113
200
300
444
750
1100
1447
1788


CFIT Simulator Study
767-200
Landing Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
Vertical Feet
Horizonal Distance in Feet
0
200
400
600
800
1000
1200
1400
1000
2000
3000
4000
5000
6000
7000
1350
1200
1049
862
764
562
418
274
186
121


CFIT Simulator Study
767-200
Landing Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
Vertical Feet
0
200
400
600
800
1000
1200
1400
0
1000
2000
3000
4000
5000
6000
7000
Horizonal Distance in Feet


CFIT Aero Study
767-300ER
Approach Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
Vertical FT
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
Horizontal Distance in Feet


CFIT Aero Study
767-300ER
Approach Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
Vertical Ft
Horizontal Distance in Feet
0
500
1000
1500
2000
2500
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
2200
2200


CFIT Aero Study
767-300ER
Landing Flaps, Sea Level
Standard 15 Deg. Pitch
Enhanced 20 Deg. Pitch
1200
1000
800
600
400
200
0
0
1000
2000
3000
4000
5000
6000
7000
Horizonal Distance in Feet
170
300
500
700
1000
1200
100
200
300
500
700
900

Go To Next Section