SWIFT 2010 CONFERENCE & TRADE SHOW

PREDICTING STOPPING DISTANCE FOR CURRENT AIRCRAFT TYPES IN AN EMAS

by

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OVERRUNS

- Aircraft overruns occur
- Majority of Aircraft involved in overruns stop within 305 m (1000-ft) of the runway end
- 90% of Aircraft involved in overruns exit the runway at < 70 knots (130 kph)
- FAA (Federal Aviation Administration) requires a 305 m (1000-ft) runway safety area
- Not satisfied at 325 of 573 US major airports (Lautenberg, 2006)
- A FAA alternative is to use an EMAS

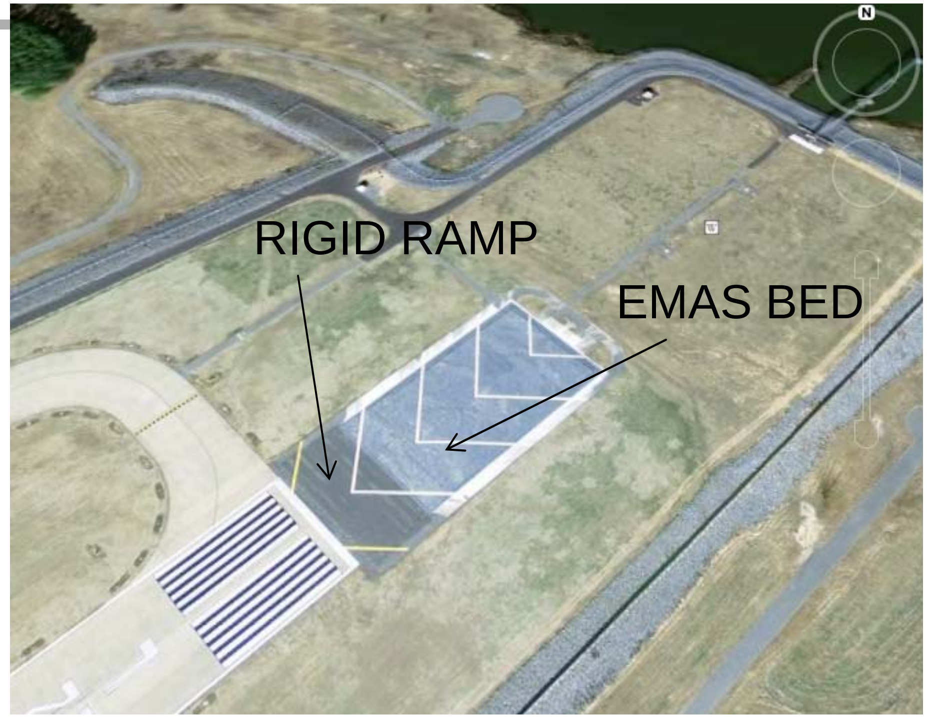
EMAS DESCRIPTION

- INSTALLED WHERE AN ADEQUATE RSA IS UNAVAILABLE (natural or manmade barriers)
- REDUCES AIRCRAFT STOPPING DISTANCE DURING OVERRUNS
- LOCATED WITHIN THE RUNWAY SAFETY AREA
- PASSIVE SYSTEM (no outside energy source, dissipates energy by inducing drag forces on aircraft landing gear)
- DESCRIBED IN FAA ADVISORY CIRCULAR 150/5220-22A

EMAS INSTALLATIONS

- 44 installations @ 30 U.S. Airports
- 4 installations @ 4 U.S. Airports under contract for 2010 installation
- 4 International Installations
  - Madrid, Spain
  - Sichuan Province, PRC

LITTLE ROCK AIRPORT (ref. GOOGLE EARTH)



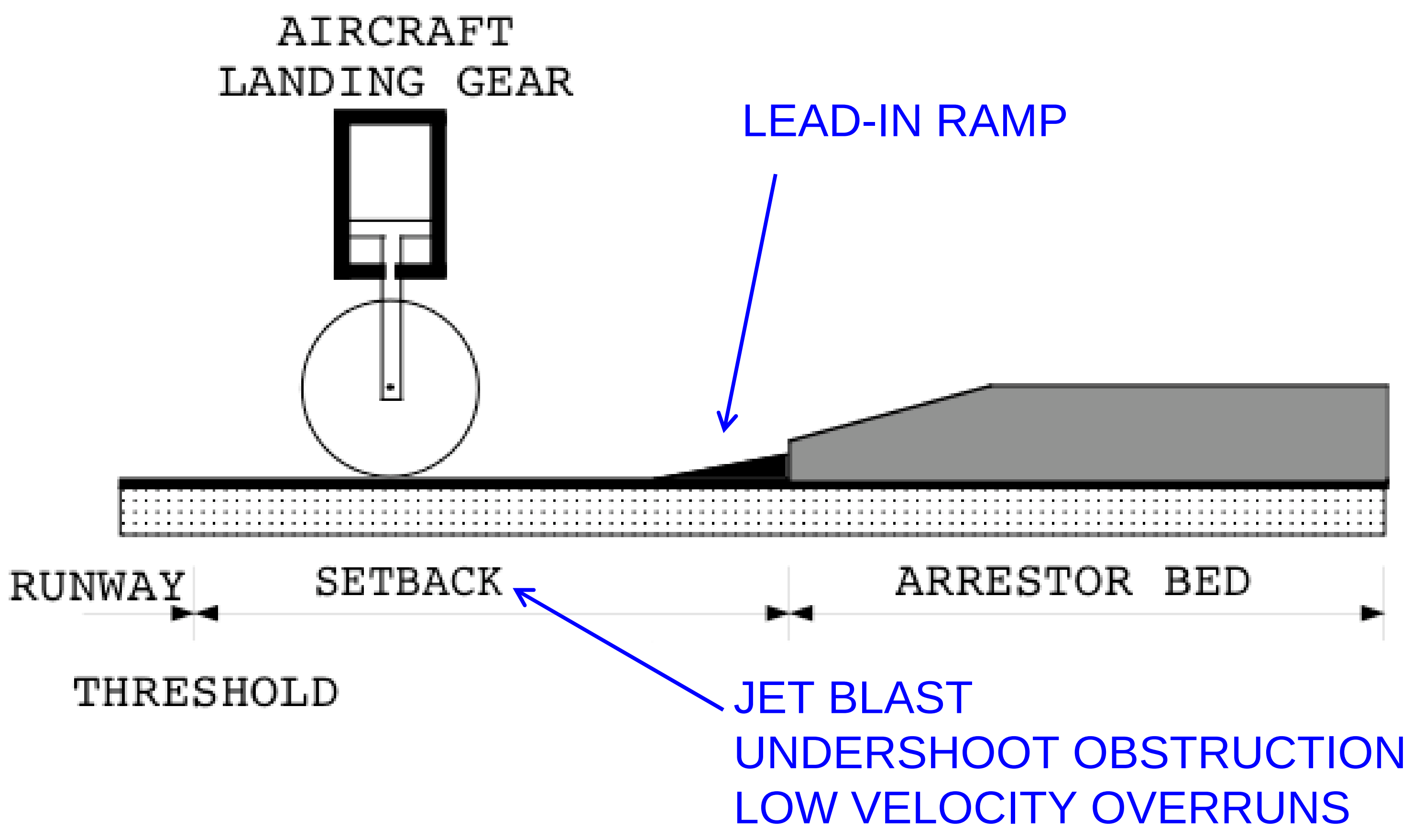
EMAS PROFILE

ENTRY

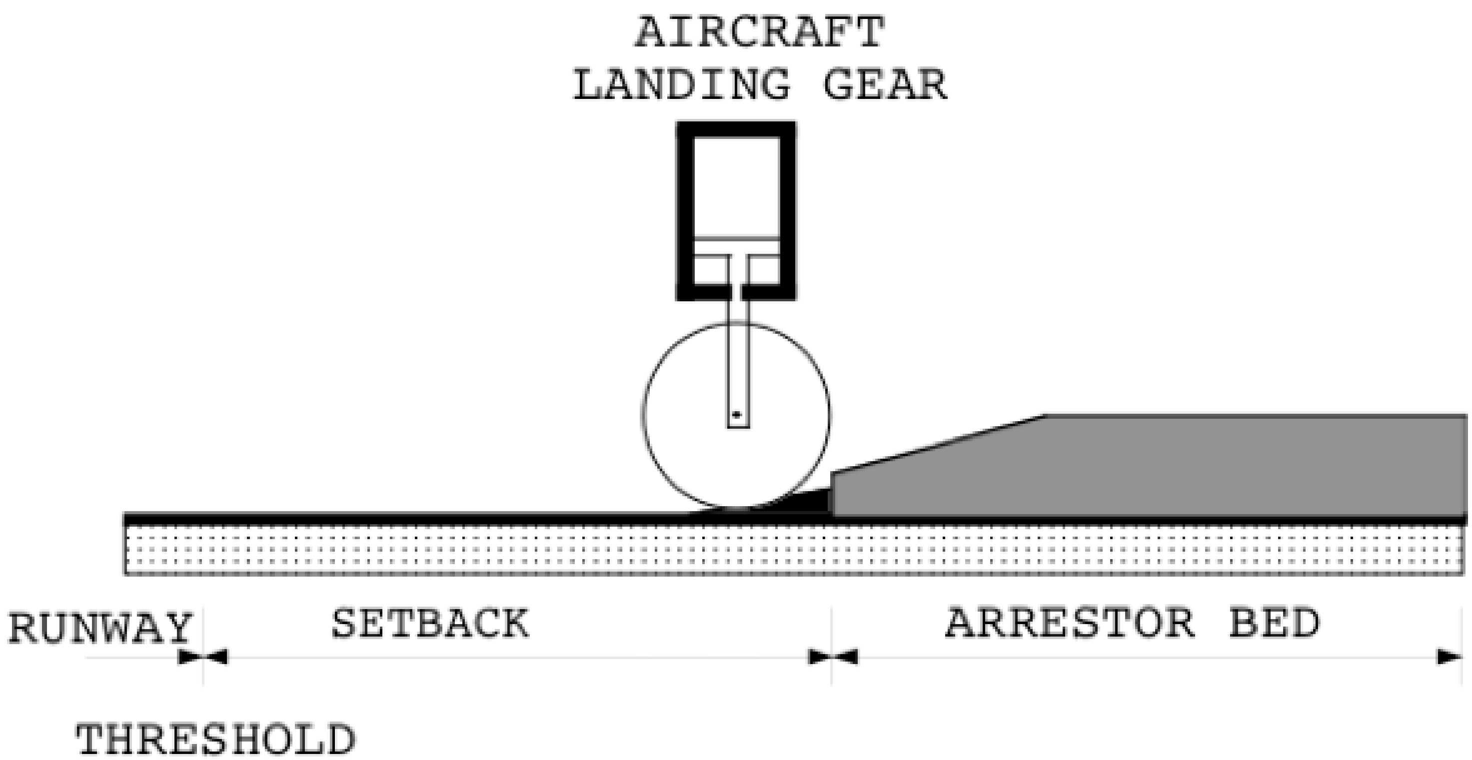
END

SIDE

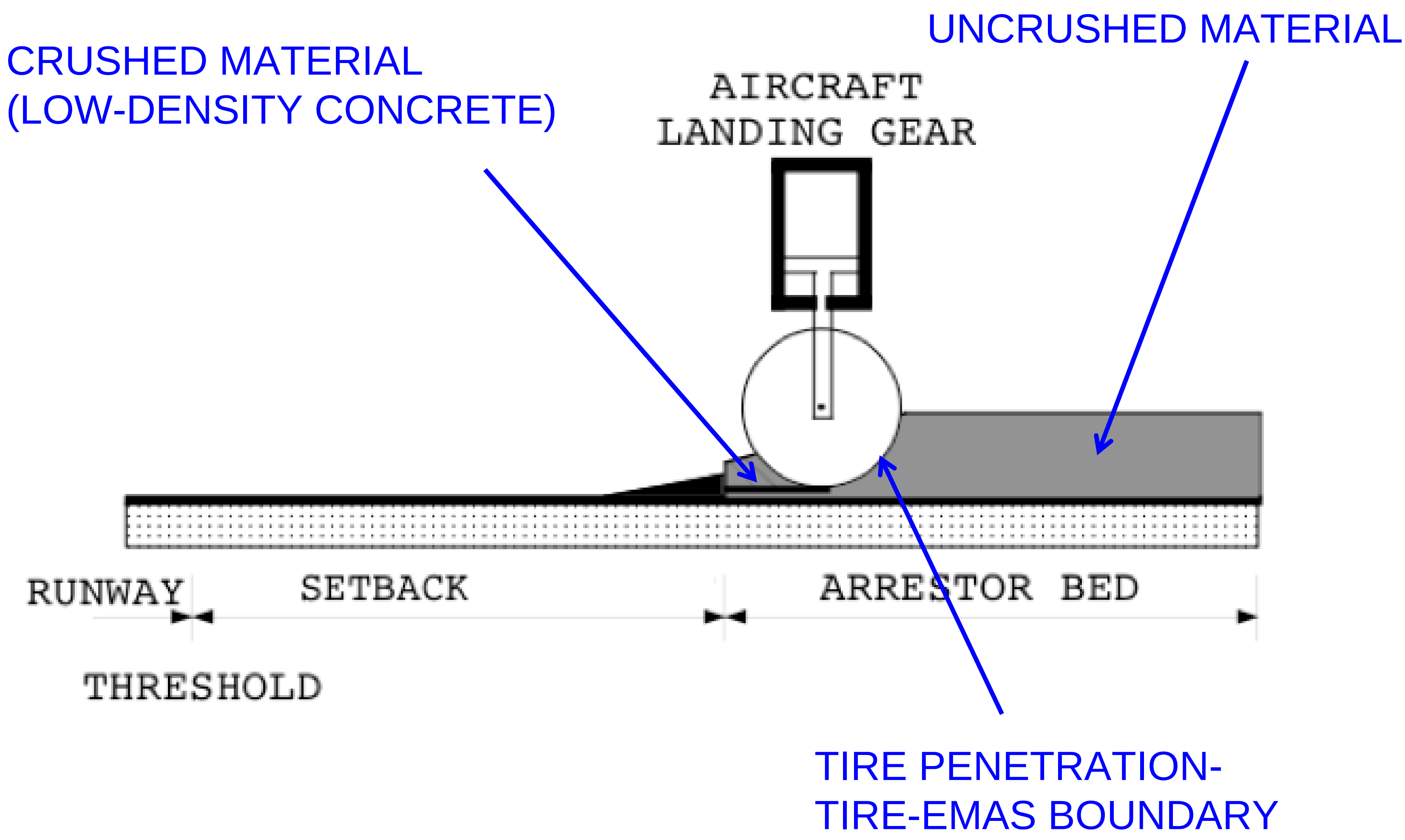
RUNWAY SAFETY AREA CONFIGURATION



RUNWAY SAFETY AREA CONFIGURATION



RUNWAY SAFETY AREA CONFIGURATION



CHARLESTON, WV USA (1/19/10)
Yeager Airport

CRJ-200: ABORTED TAKEOFF
(30 passengers, 1 infant, & 3 crew members)

INSTALLED 11/08 ($5 million)
EMAS LENGTH = 130m (425 ft)
SD = 91m (300 ft)

APPROXIMATE VALUES FOR AIRCRAFT PARAMETERS

(STOPPING DISTANCE ANALYSIS FOR CURRENT AIRCRAFT TYPES)

AIRCRAFT CHARACTERISTICS:

- AIRPLANE DIMENSIONS AND LOADS
- WHEEL BEHAVIOR (LOAD-DEFL)
- STRUT BEHAVIOR (LOAD-STROKE)

AIRPLANE CHARACTERISTICS (DIMENSIONS & LOADS)

AIRPLANE CHARACTERISTICS FOR AIRPORT PLANNING

BOEING:
http://www.boeing.com/commercial/airports/plan_manuals.html

AIRBUS:
http://www.airbus.com/index.php?id=299

TIRE STIFFNESS

- TIRE MANUFACTURERS

(Goodrich, Goodyear, Michelin)

AIRCRAFT PARAMETERS

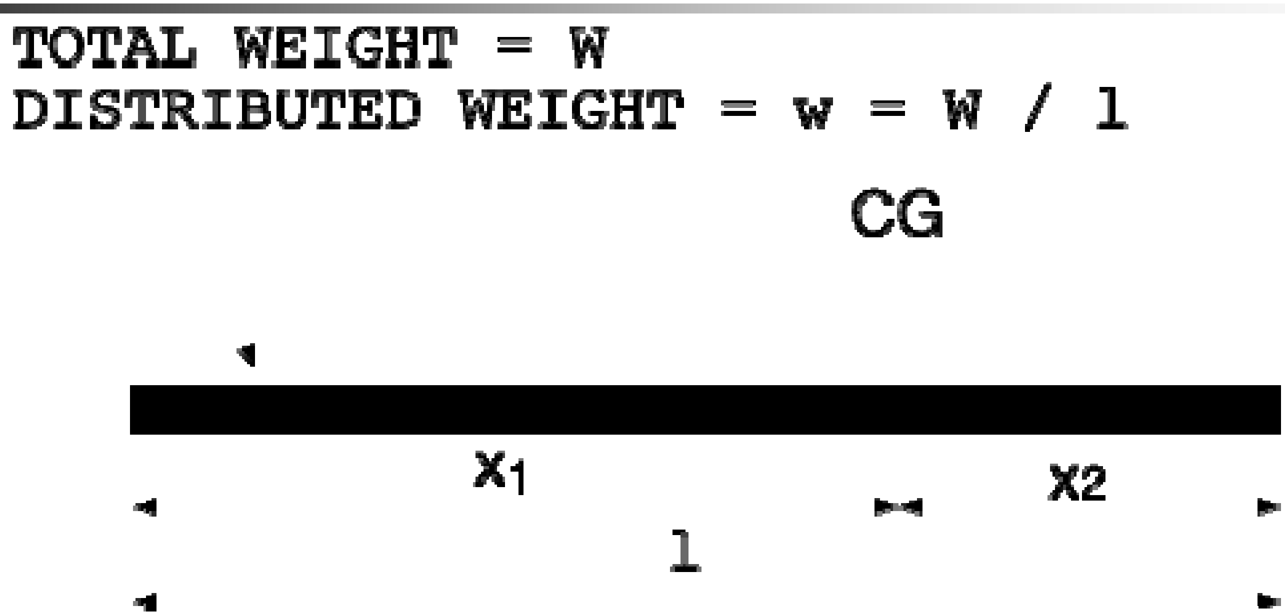
- Gerardi, A.G., “Collection of Commercial Characteristics for Study of Runway Roughness,” Report No. FAA-RD-76-64, FAA, 1977

AIRCRAFT PARAMETERS (ref: Gerardi)

AIRCRAFT TYPE		DC-9-41	B727-200	B707-320C	DC-10-10	B747-200
GROSS WT.	N	507,300	712,000	1,361,700	1,958,000	2,803,500
MOM. of INERTIA	$kg*m^2$	2,435,825	7,101,662	9,578,197	23,928,531	55,184,892
DIMENSIONS						
NG (# TIRES)		2	2	2	2	2
MG CONFIG		DUAL	DUAL	DUAL TAND.	DUAL TAND.	DUAL TAND.
NG-CG DIST	m	16.58	18.23	17.23	20.30	23.26
CG-MG1 DIST	m	0.62	0.98	0.76	1.85	0.81
CG-MG2 DIST	m					3.89
LOAD / STRUT						
MAX VERT LOAD						
NOSE GEAR	N	76,630	113,920	230,400	378,100	603,900
MAIN GEAR	N	239,500	390,710	698,700	950,900	817,910
UNSPRUNG WT						
NOSE GEAR	N	730	2,203	1,922	2,901	7,790
MAIN GEAR	N	4,779	6,065	7,383	22,713	17,355
MAX STROKE						
NOSE GEAR	mm	389	307	434	437	640
MAIN GEAR	mm	452	356	589	622	732
DAMPING COEF.						
NOSE GEAR	$N/(mm/s)^2$	0.002	0.023	0.022	0.257	0.068
MAIN GEAR	$N/(mm/s)^2$	0.004	0.026	0.120	0.285	0.063

MASS MOMENT of INERTIA, Iyy

PITCH MOMENT OF INERTIA



$$I_{yy}(calc) = \int r^2 dm = \int r^2 \frac{w}{g} dr = \frac{W}{gl} \int r^2 dr = \frac{W}{3gl}(x_1^3 + x_2^3)$$

MASS MOMENT of INERTIA, Iyy

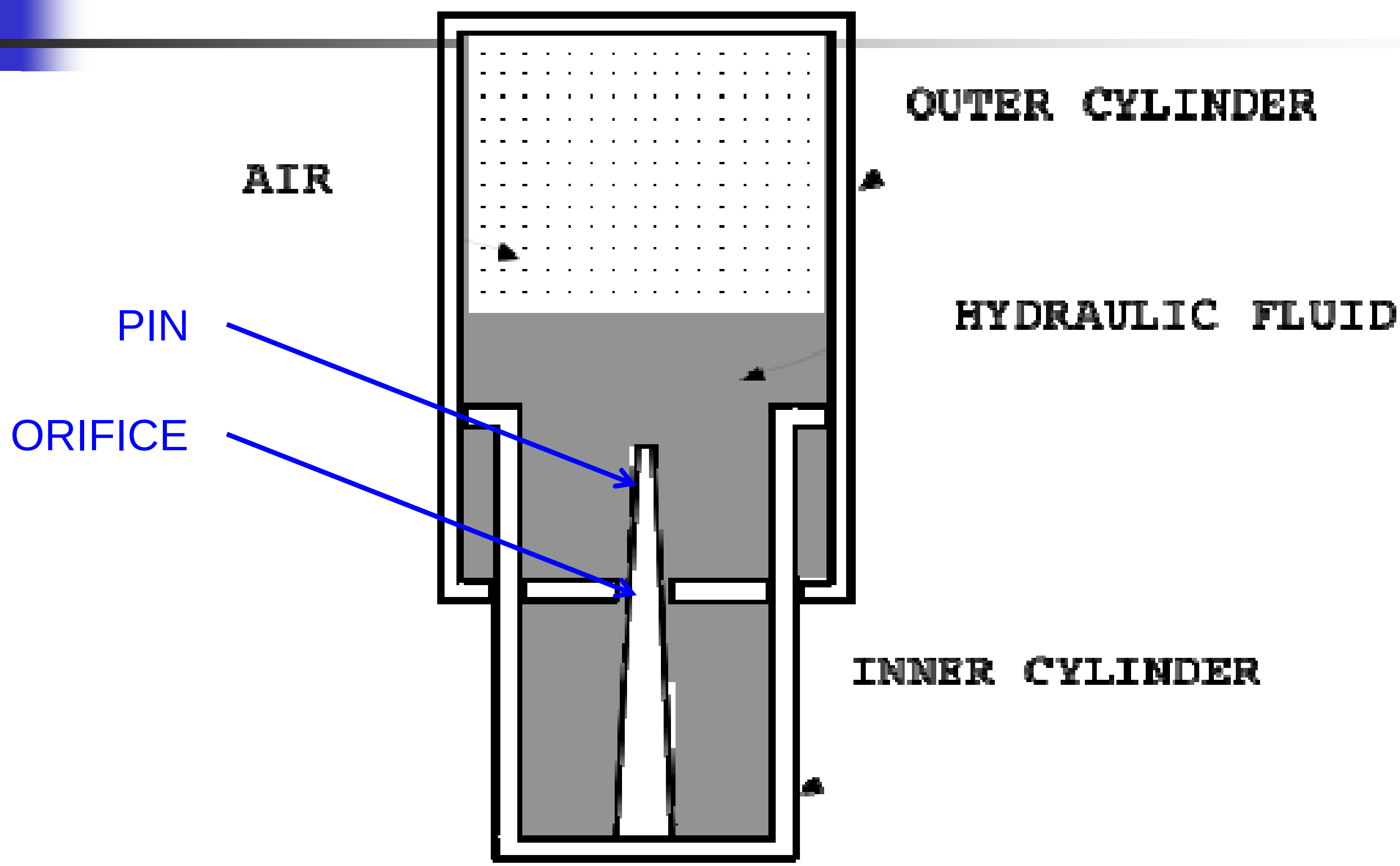
AIRCRAFT TYPE	GW (N)	TOTAL LENGTH, l (m)	x_1 (m)	Iyy (rod) ($kg*m^2$)	Iyy (given) ($kg*m^2$)	CORRECTION FACTOR
DC-9-41	507300	34.54	19.42	5,380,843	2,435,825	0.45
B727-200	712000	41.52	23.88	11,134,862	7,101,662	0.64
B707-320C	1361700	44.36	23.30	22,935,730	9,578,197	0.42
DC-10-10	1958000	51.98	30.58	49,139,693	23,928,531	0.49
B747-200	2803500	68.65	33.36	112,499,894	55,184,892	0.49
"BEST ESTIMATE" CORRECTION FACTOR =				**0.45**		
						Iyy (modified) ($kg*m^2$)
B737-900ER	760950	40.68	21.27	10,762,107		4,842,948
B747-400ER	4049500	68.65	33.36	162,499,846		73,124,931
B757-300	1201500	54.45	28.25	30,384,663		13,673,098
B767-400ER	2002500	60.10	30.72	61,534,663		27,690,598

UNSPRUNG WEIGHTS (wheel module)

AIRCRAFT	DC-9-41	B727-200	B707-320C	DC-10-10	B747-200
UNSPRUNG WT (N)					
NOSE GEAR	730	2,203	1,922	2,901	7,788
MAIN LANDING	4,779	6,065	7,383	22,714	17,355
MAX VERT LOAD (N)					
NG (BREAKING)	76,629	113,920	230,377	378,068	603,865
MG (AFT)	239,486	390,710	698,650	950,876	817,910
NG UNSPR. WT. RATIO	0.010	0.019	0.008	0.008	0.013
MG UNSPR. WT. RATIO	0.020	0.016	0.011	0.024	0.021
"BEST ESTIMATE" (NG UNSPRUNG WT / MAX VERTICAL NG LOAD) = 0.01					
"BEST ESTIMATE" (MG UNSPRUNG WT / MAX VERTICAL MG LOAD) = 0.02					
AIRCRAFT	**B737-900ER**	**B747-400ER**	**B757-300**	**B767-400ER**	
MAX VERT LOAD (N)					
NG (BREAKING)	110,405	544,680	190,460	265,443	
MG (AFT)	396,019	950,520	558,475	942,733	
NG UNSPR. WT. RATIO	0.01	0.01	0.01	0.01	
MG UNSPR. WT. RATIO	0.02	0.02	0.02	0.02	
UNSPRUNG WT (N)					
NOSE GEAR	1,104	5,447	1,905	2,654	
MAIN LANDING	7,920	19,010	11,170	18,855	

STRUT BEHAVIOR

OLEO-PNEUMATIC STRUT

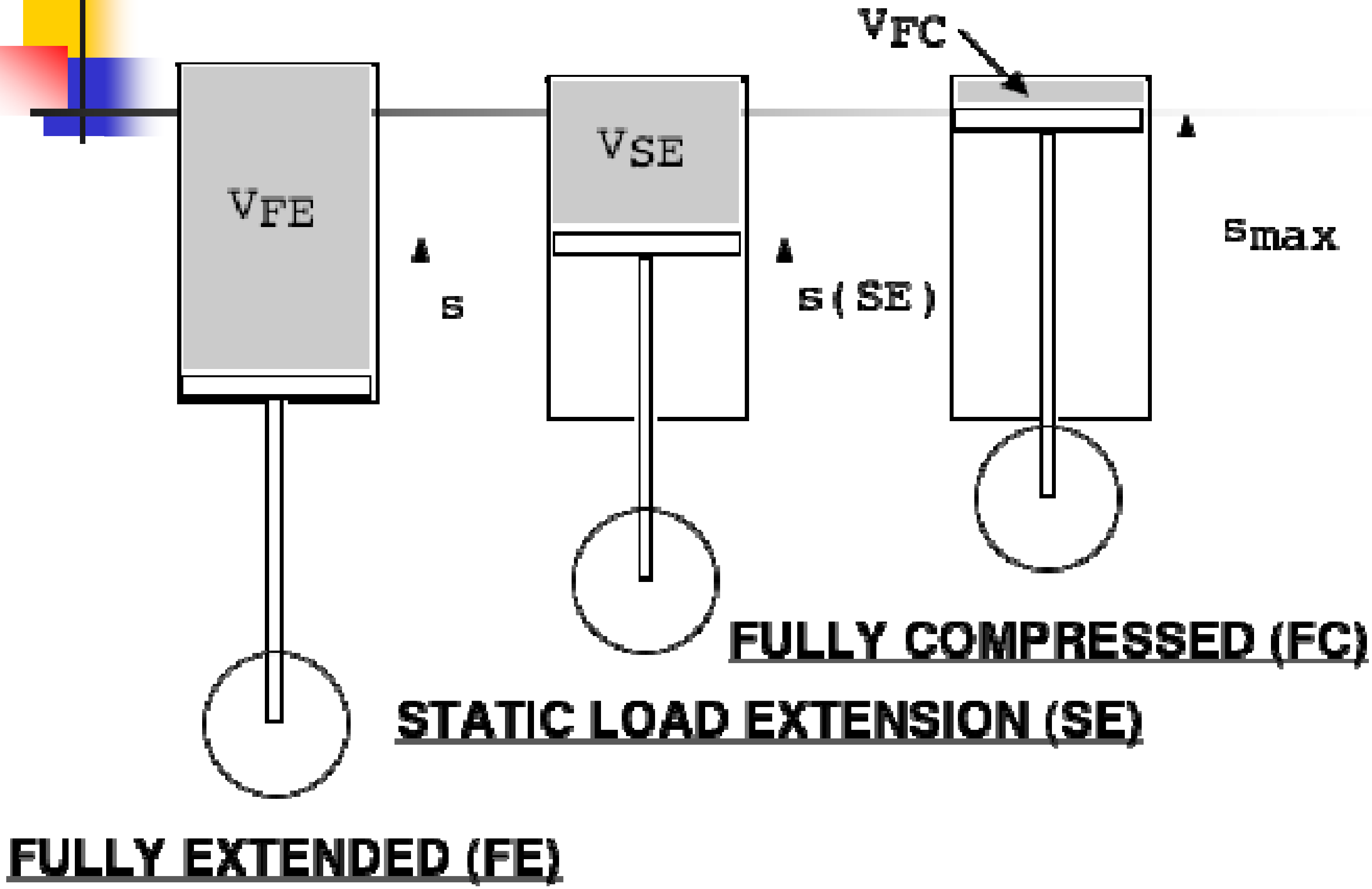


MAXIMUM STROKE & DAMPING

AIRCRAFT	**DC-9-41**	**B727-200**	**B707-320C**	**DC-10-10**	**B747-200**
GROSS WT. (N)	507,300	822,360	1,484,520	1,913,500	3,448,750
MAX NG VERT LOAD (N)	76,629	113,920	230,377	378,068	603,865
MAX STROKE @ NG (mm)	389	307	434	437	640
NG DAMPING COEF. (1/(mm/sec^2))	0.01	0.13	0.12	1.47	0.39
MAX MG VERT LOAD (N)	239,486	390,710	698,650	950,876	817,910
MAX STROKE @ MG (mm)	452	356	589	622	732
MAX STROKE @ MG2 (mm)					719
MG DAMPING COEF. (1/(mm/sec^2))	0.02	0.15	0.68	1.63	0.36
MG2 DAMPING COEF. (1/(mm/sec^2))					0.54

AIRCRAFT	**B737-900ER**	**B747-400ER**	**B757-300**	**B767-400ER**	
GROSS WT. (N)	760,950	4,049,500	1,201,500	2,002,500	
SIMILAR AIRCRAFT WT.	**B727-200**	**B747-200**	**B727-200**	**DC-10-10**	
MAX NG VERT LOAD (N)	110,405	544,680	190,460	265,443	
"BEST ESTIMATE VALUES"					
MAX STROKE @ NG (mm)	305	635	305	432	
NG DAMPING COEF. (1/(mm/sec2))	0.16	0.39	0.16	0.39	
MAX MG VERT LOAD (lb)	396,019	950,520	558,475	942,733	
"BEST ESTIMATE VALUES"					
MAX STROKE @ MG (mm)	356	762	356	610	
MAX STROKE @ MG2 (mm)				610	
MG DAMPING COEF. (1/(mm/sec^2))	0.16	0.39	0.16	0.39	
MG2 DAMPING COEF. (1/(mm/sec^2))				0.39	

PNEUMATIC STRUT FORCE



APPROXIMATIONS

(ref. Curry, Aircraft & Landing Gear Design: Principles & Practices)

- V(static strut load) = Airport Planning Guide
- S_{MAX} = similar “Gerardi” aircraft
- p_{gage} (SE) = 10,335 kPa (1,500 psi)
- p_{gage} (FE) / p_{gage} (SE) = 0.25
  - p_{gage} (FE) = 2,580 kPa (375 psi)
- p_{gage} (FC) / p_{gage} (SE) = 3.0
  - p_{gage} (FC) = 31,000 kPa (4,500 psi)

IDEAL GAS LAW

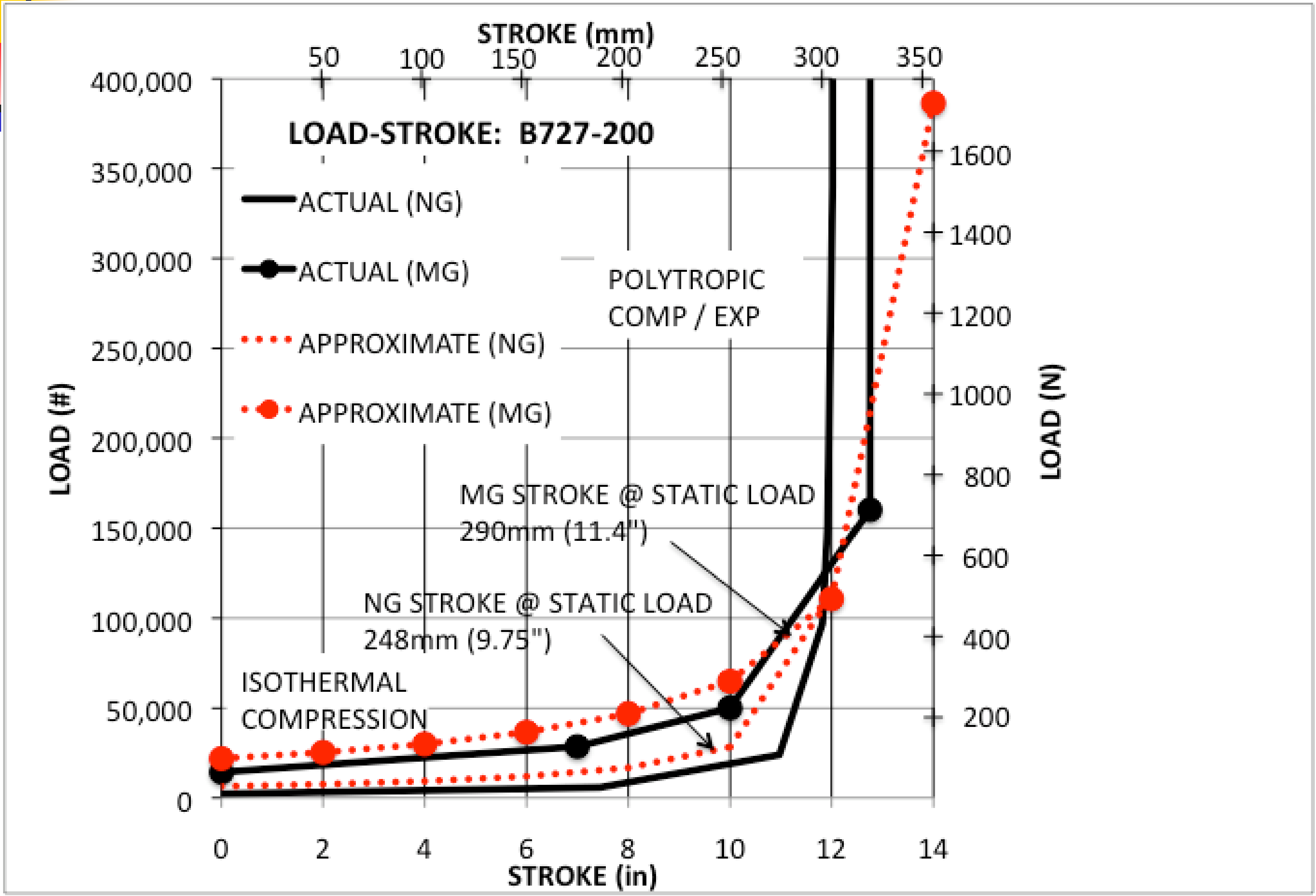
- ISOTHERMAL COMPRESSION / EXPANSION

$$p_{gage}(S) = \frac{p_{abs}(SE) * V_{SE}}{V(S)} - p_{atm}$$

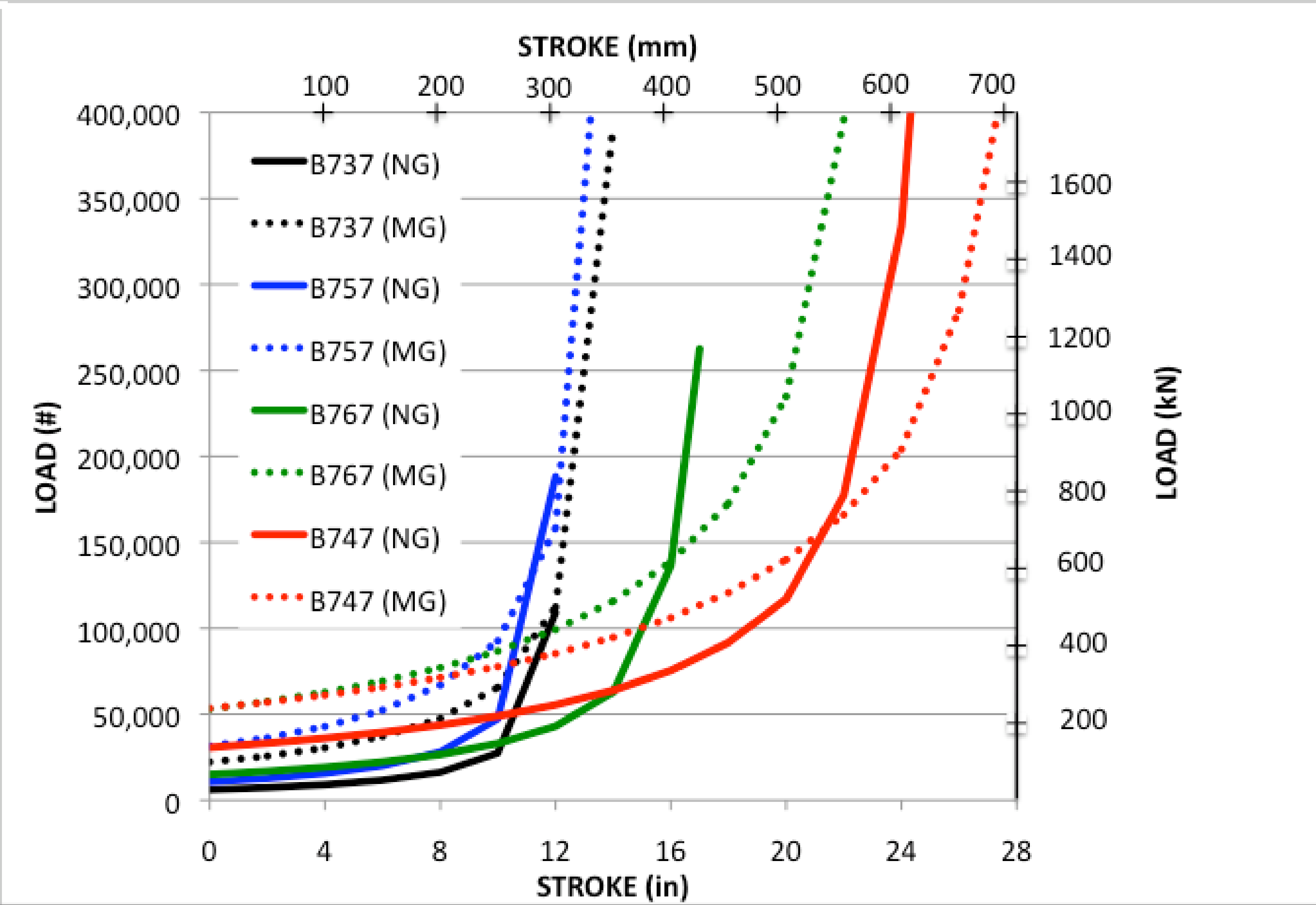
- POLYTROPIC COMPRESSION / EXPANSION

$$p_{gage}(S) = \frac{p_{abs}(SE) * V_{SE}^{1.35}}{V(S)} - p_{atm}$$

B727-200: LOAD-STROKE



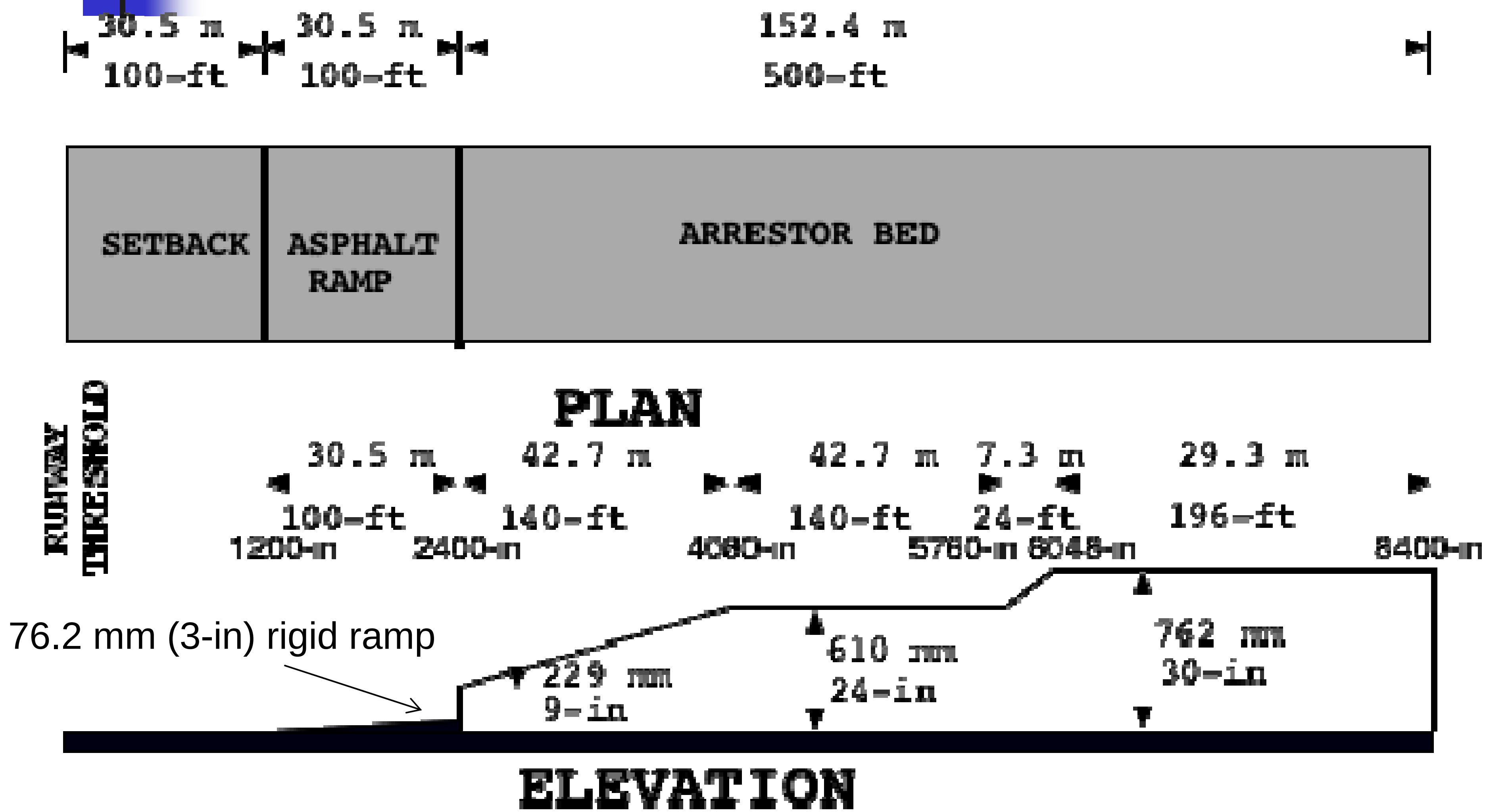
LOAD-STROKE APPROXIMATE BEHAVIOR



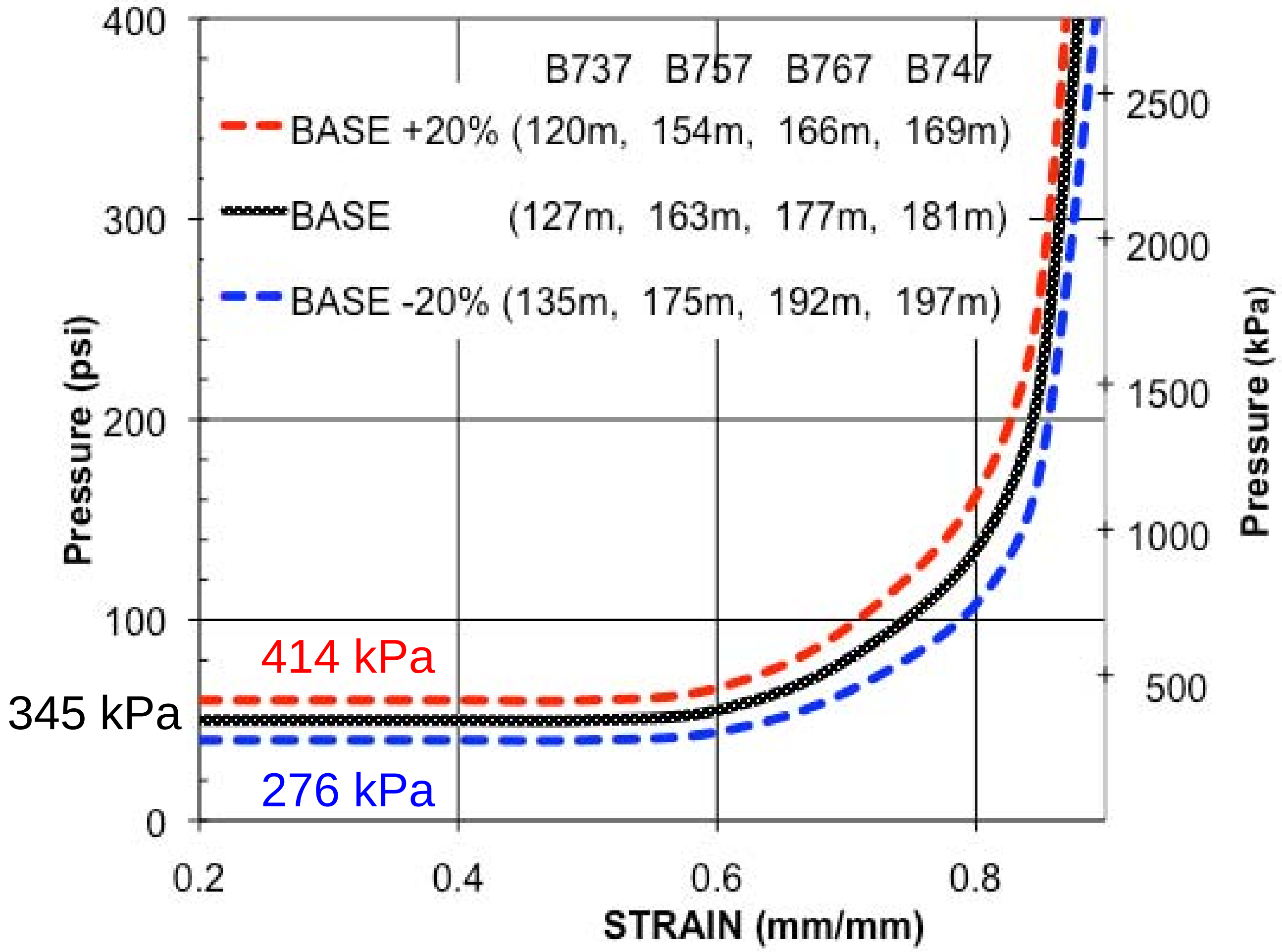
STOPPING DISTANCE SENSITIVITY STUDY

- VARIABILITY IN MATERIAL STRESS-STRAIN BEHAVIOR (±20%)
- ARRESTOR MATERIAL STRENGTH
- ARRESTOR BED THICKNESS

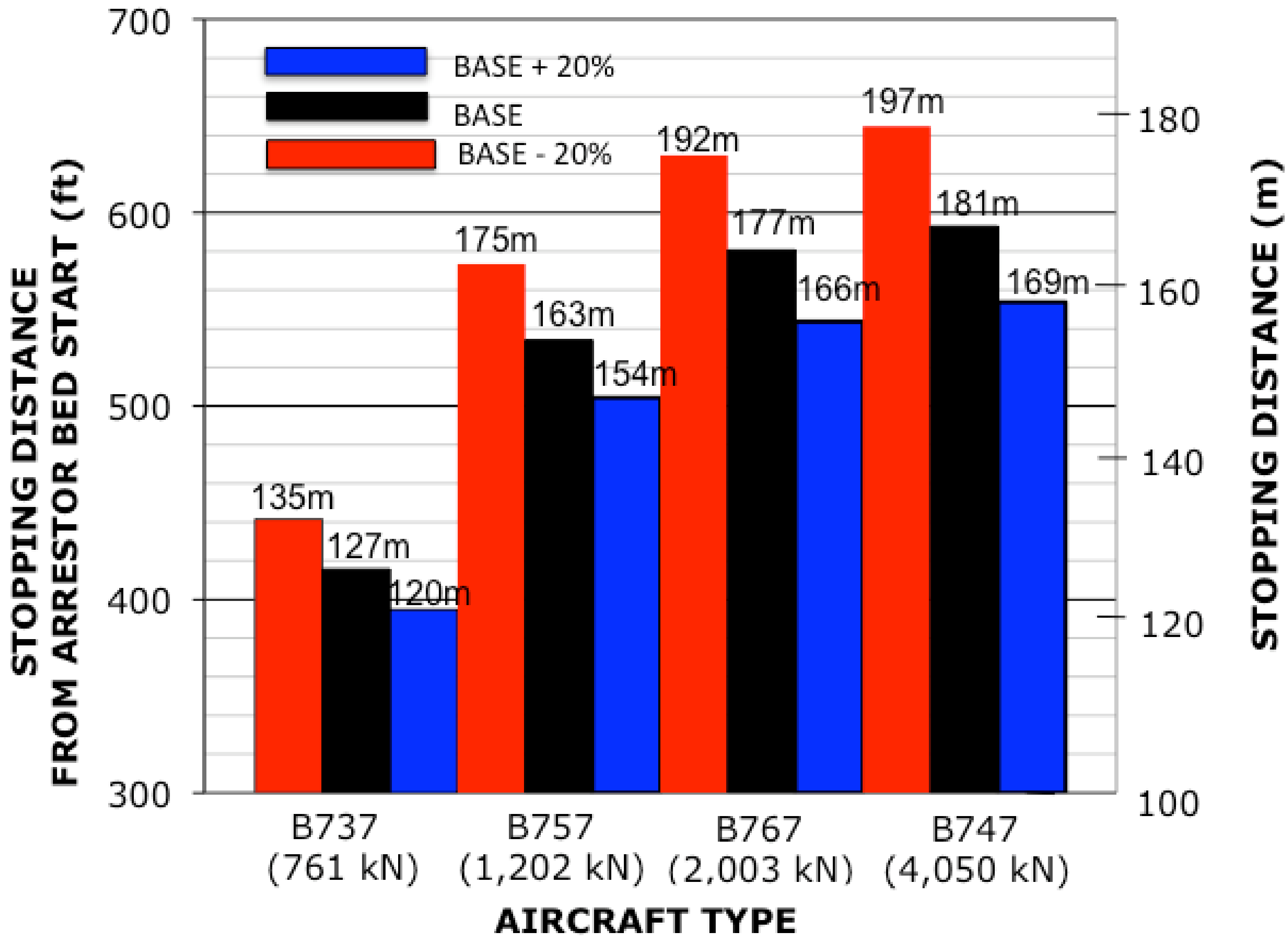
EMAS BED GEOMETRY



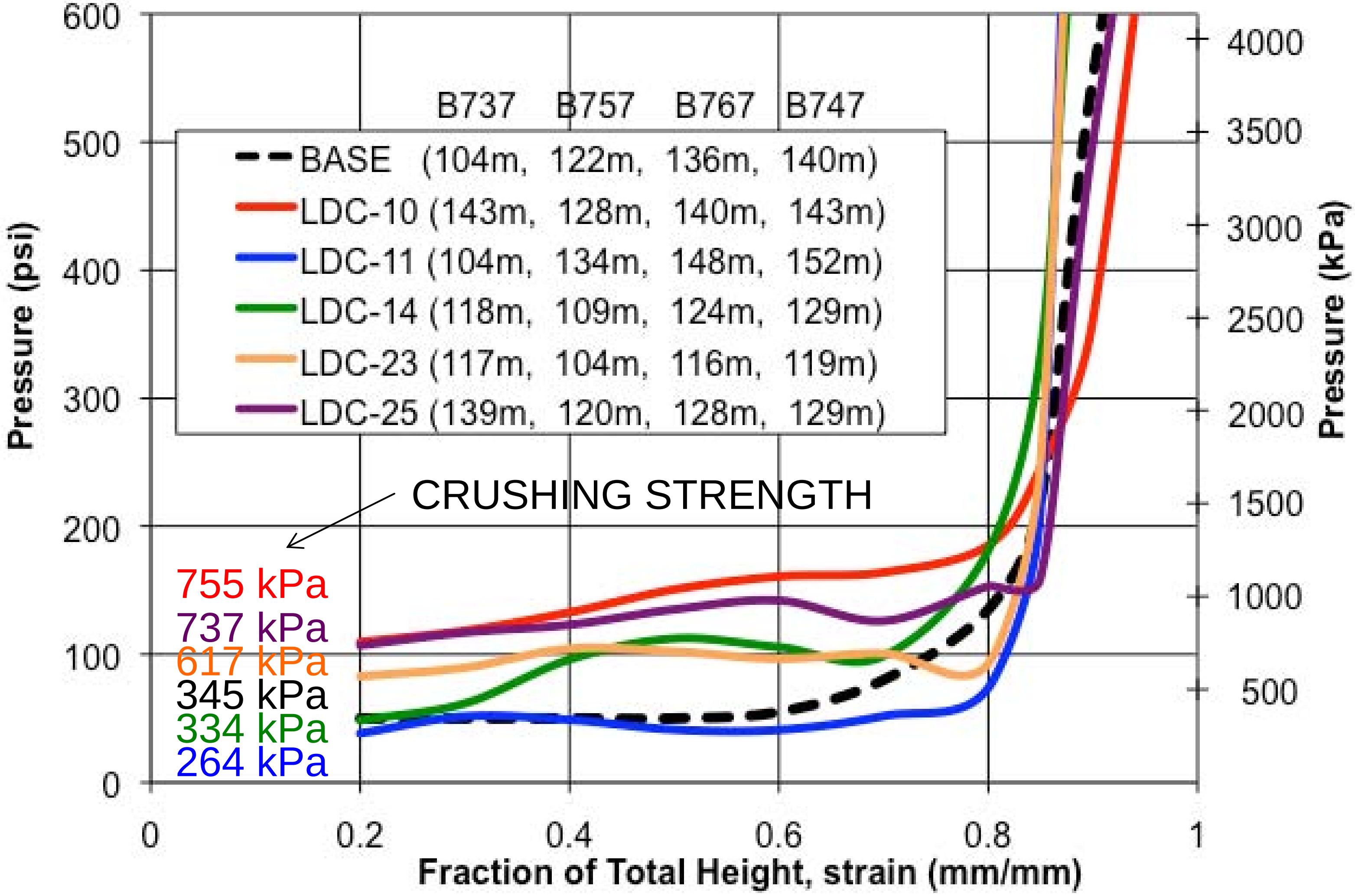
MATERIAL STRESS-STRAIN BEHAVIOR



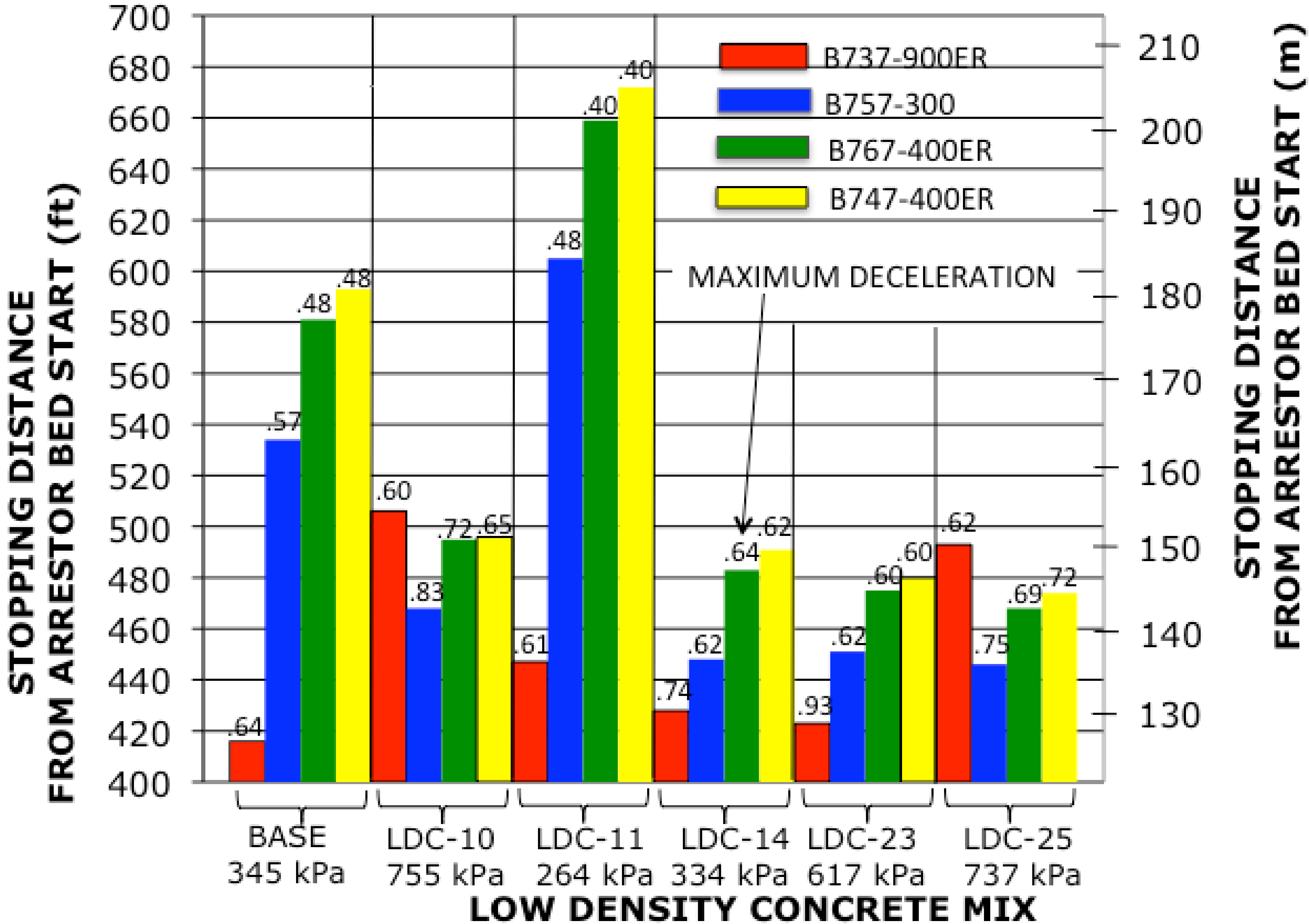
STOPPING DISTANCE = f(material behavior)



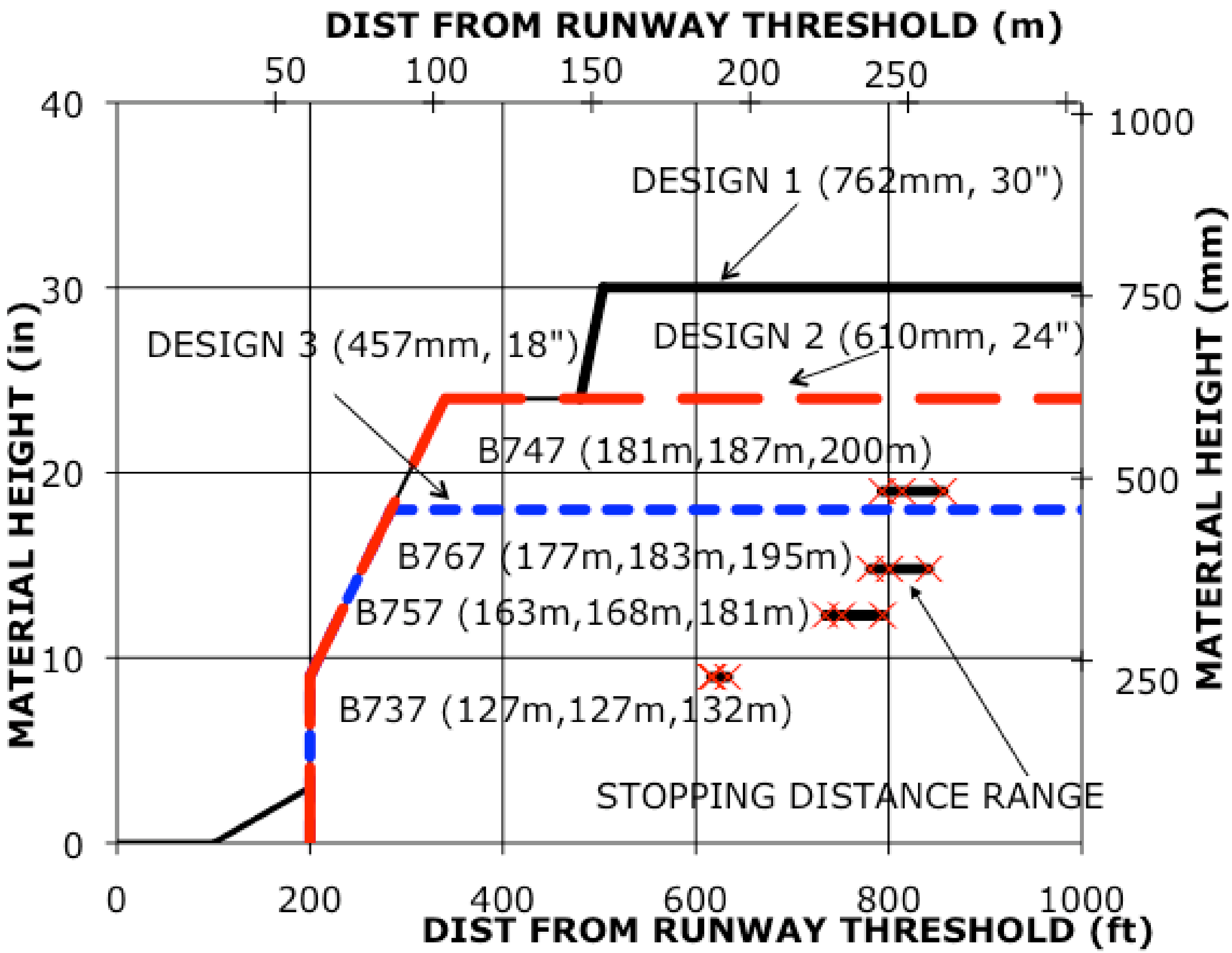
ARRESTOR MATERIAL STRESS-STRAIN BEHAVIOR



ARRESTOR MATERIAL STRESS-STRAIN BEHAVIOR



STOPPING DISTANCE = f(EMAS MAX THICKNESS)



CONCLUSIONS

- 44 EMAS INSTALLATIONS @ 30 U.S. AIRPORTS (4 @ 2 INTL. AIRPORTS)
- METHODOLGY TO GENERATE APPROXIMATE AIRCRAFT PARAMETERS
- 4 AIRCRAFT TYPES EVALUATED (B737, B747, B757, & B767)

CONCLUSIONS

- STOPPING DISTANCE DEPENDENCY ON:
  - AIRCRAFT TYPE (B737, B747, B757, & B767)
  - MATL. STRESS-STRAIN BEHAVIOR (± 20%)
  - MATL. STRENGTH (6 low density conc. mixes)
  - BED THICKNESS (t_{max}= 457mm, 610mm, & 762mm (18 in, 24 in, & 30 in))

ACKNOWLEGEMENTS

- Mack-Blackwell Transportation Center
- The Strong Company
- Dr. Micah Hale, experimental work

GO RAZORBACKS!

University of ARKANSAS
RAZORBACKS

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