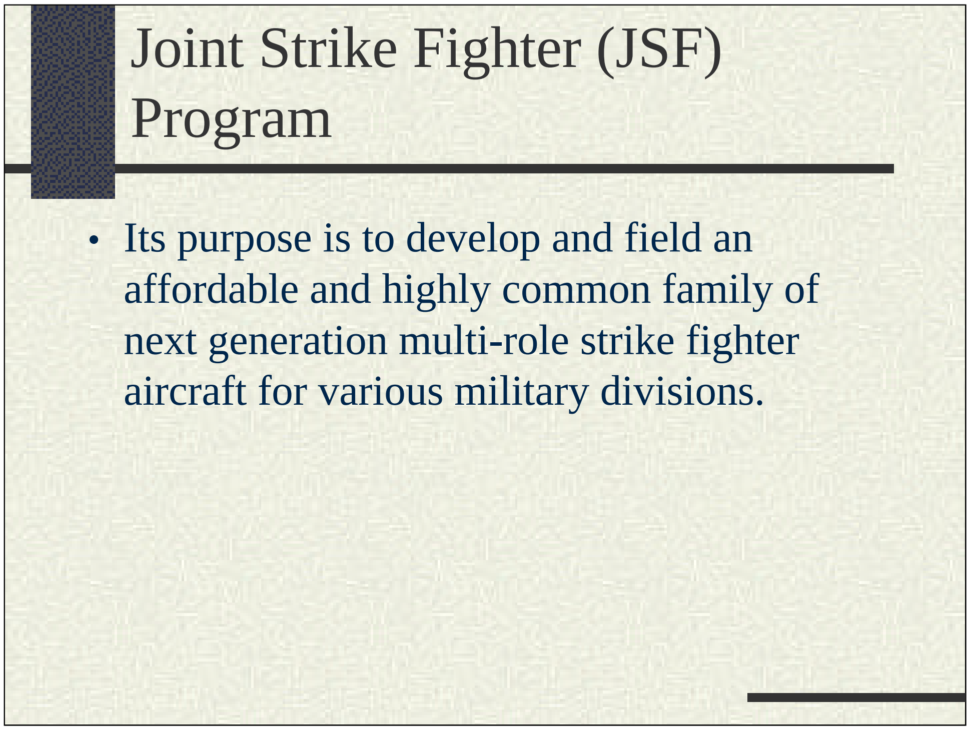
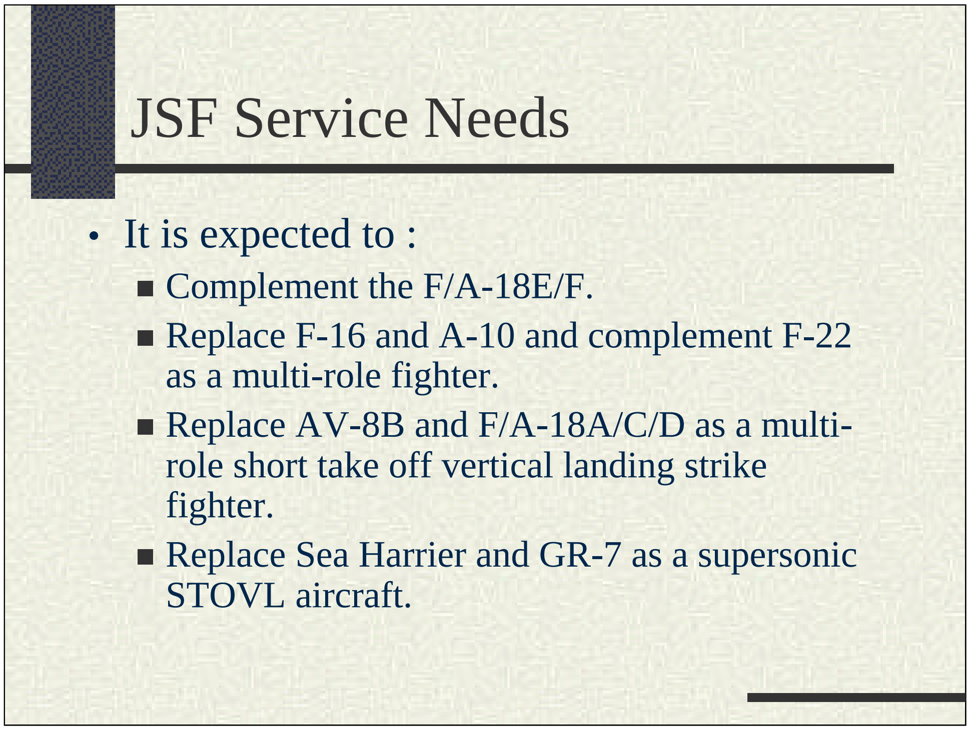
The Fighter of the 21st Century

Presented By Michael Weisman
Configuration Aerodynamics
4/23/01



Joint Strike Fighter (JSF) Program

- Its purpose is to develop and field an affordable and highly common family of next generation multi-role strike fighter aircraft for various military divisions.



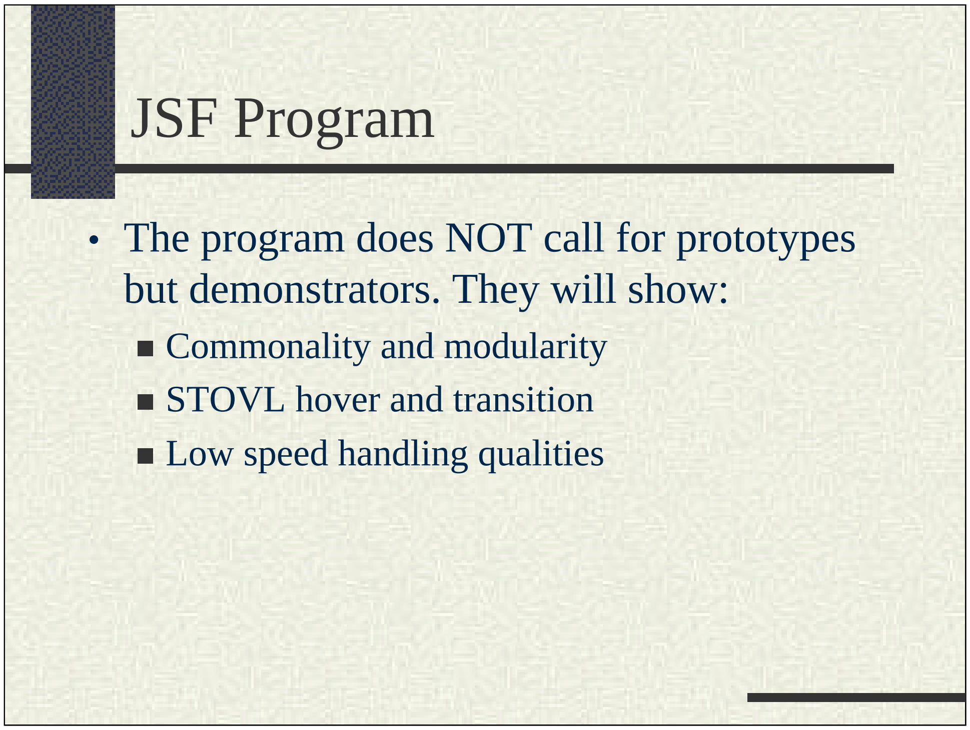
JSF Service Needs

- It is expected to :
  - Complement the F/A-18E/F.
  - Replace F-16 and A-10 and complement F-22 as a multi-role fighter.
  - Replace AV-8B and F/A-18A/C/D as a multi-role short take off vertical landing strike fighter.
  - Replace Sea Harrier and GR-7 as a supersonic STOVL aircraft.

It should be noted :

-The replacement and complement requirements were found within the JSF Whitepaper document. This document giving a brief overview of the program can be acquired at:

http://www.jast.mil/NSFrames.htm



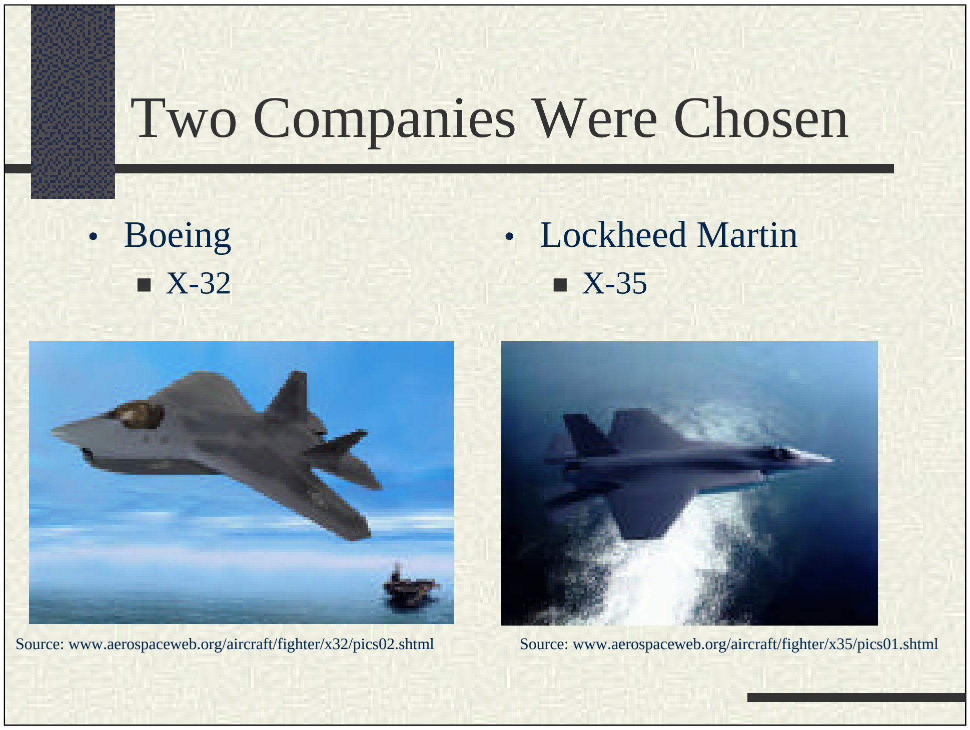
JSF Program

- The program does NOT call for prototypes but demonstrators. They will show:
  - Commonality and modularity
  - STOVL hover and transition
  - Low speed handling qualities

It should be noted:

-Commonality, in this case, is defined by 70% to 90% of the parts should be interchangeable between the three variants.

-The Boeing X-32’s demonstrator does not contain a tail, however the final design will.

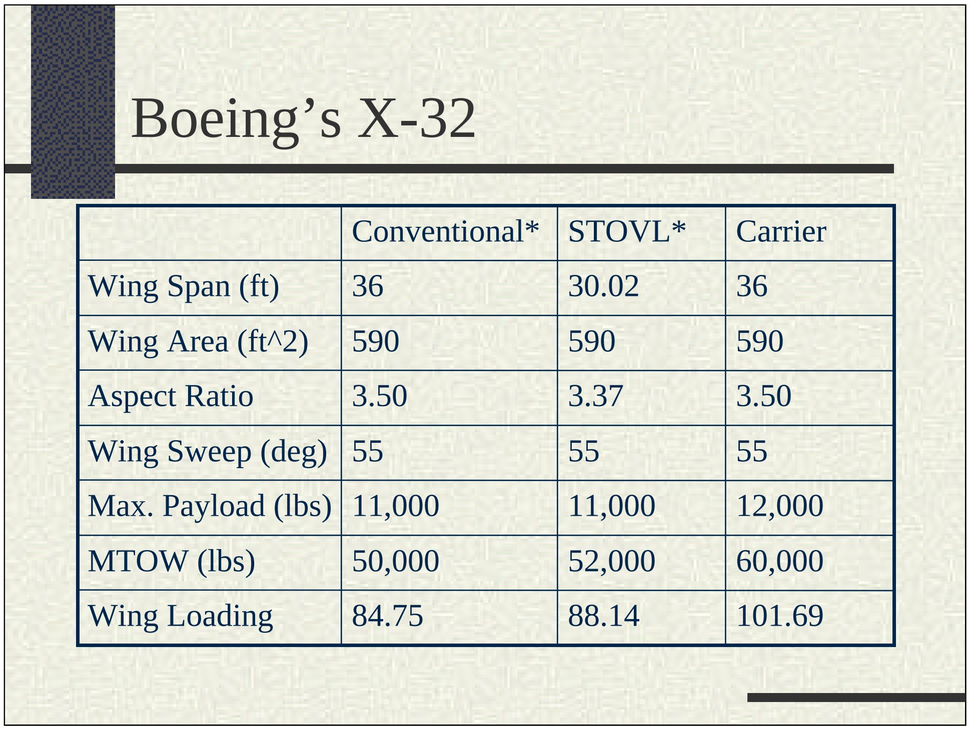


Two Companies Were Chosen

- Boeing
  - X-32
- Lockheed Martin
  - X-35

Source: www.aerospaceweb.org/aircraft/fighter/x32/pics02.shtml

Source: www.aerospaceweb.org/aircraft/fighter/x35/pics01.shtml



Boeing’s X-32

	Conventional*	STOVL*	Carrier
Wing Span (ft)	36	30.02	36
Wing Area (ft^2)	590	590	590
Aspect Ratio	3.50	3.37	3.50
Wing Sweep (deg)	55	55	55
Max. Payload (lbs)	11,000	11,000	12,000
MTOW (lbs)	50,000	52,000	60,000
Wing Loading	84.75	88.14	101.69

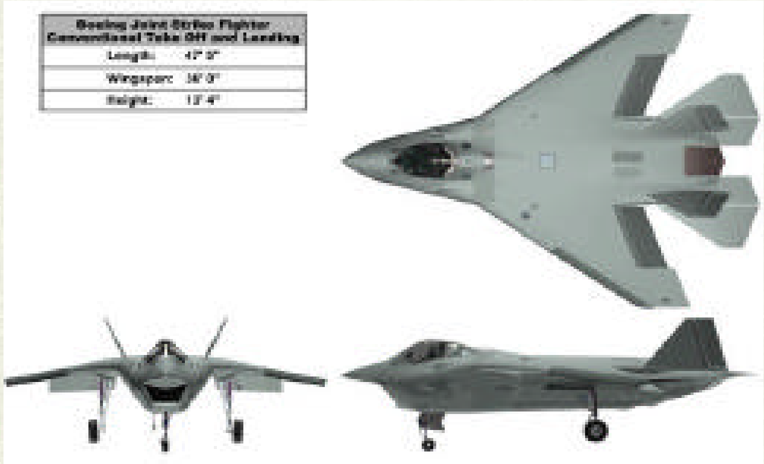
It should be noted that:

-The stars indicate those variants were actually built. The remaining variant was produced by modifying the conventional landing design.

-The Aspect Ratio was calculated using the equation for an arrow wing planform:

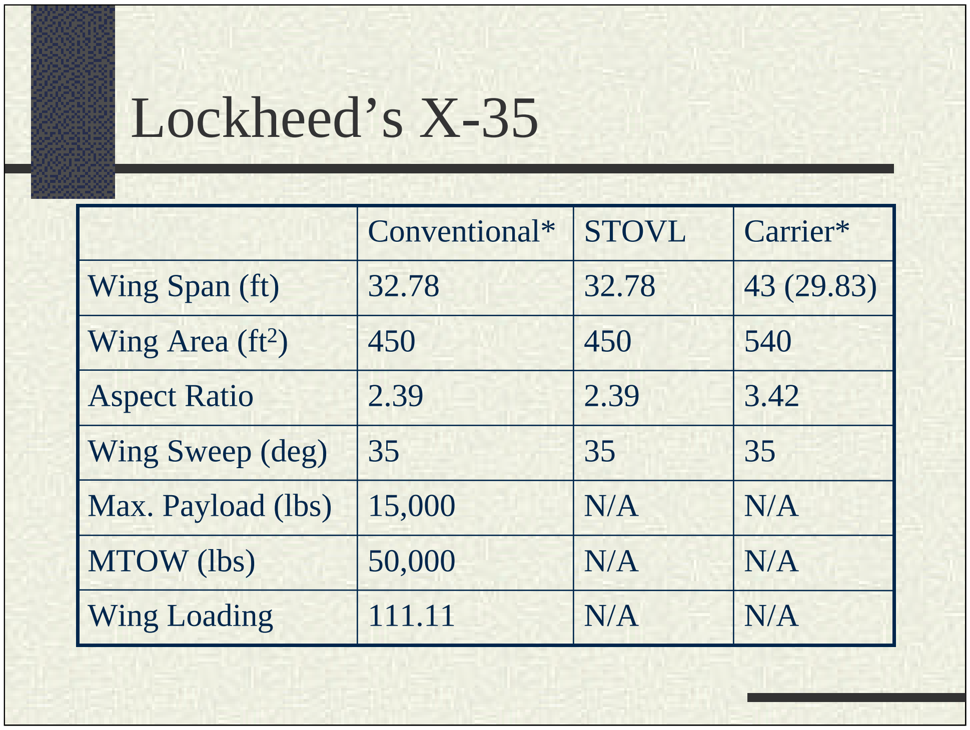
$AR = 4/[(1-z)\tan L]$

Boeing’s X-32



Boeing Joint Strike Fighter Conventional Take Off and Landing	
Length:	47' 0"
Wingspan:	36' 0"
Height:	13' 4"

Source: www.aerospaceweb.org/aircraft/fighter/x32/data.shtml



Lockheed’s X-35

	Conventional*	STOVL	Carrier*
Wing Span (ft)	32.78	32.78	43 (29.83)
Wing Area (ft^2)	450	450	540
Aspect Ratio	2.39	2.39	3.42
Wing Sweep (deg)	35	35	35
Max. Payload (lbs)	15,000	N/A	N/A
MTOW (lbs)	50,000	N/A	N/A
Wing Loading	111.11	N/A	N/A

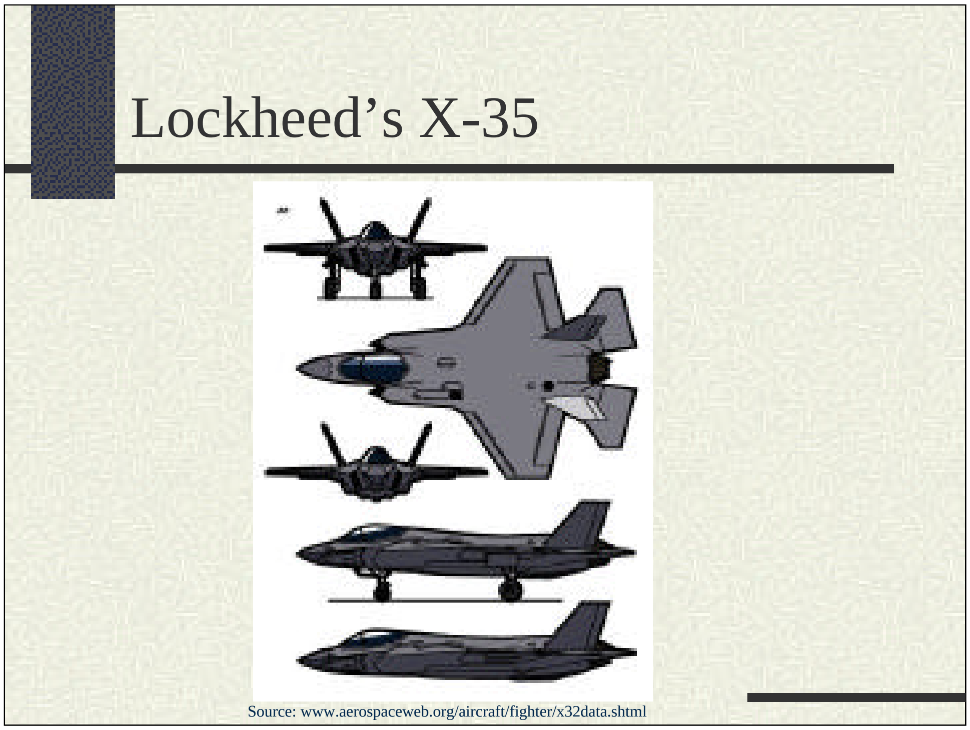
It should be noted:

-The stars indicate those variants were actually built. The remaining variant was produced by modifying the conventional landing design.

-The Aspect Ratio was calculated using the equation for a trapezoidal wing planform:

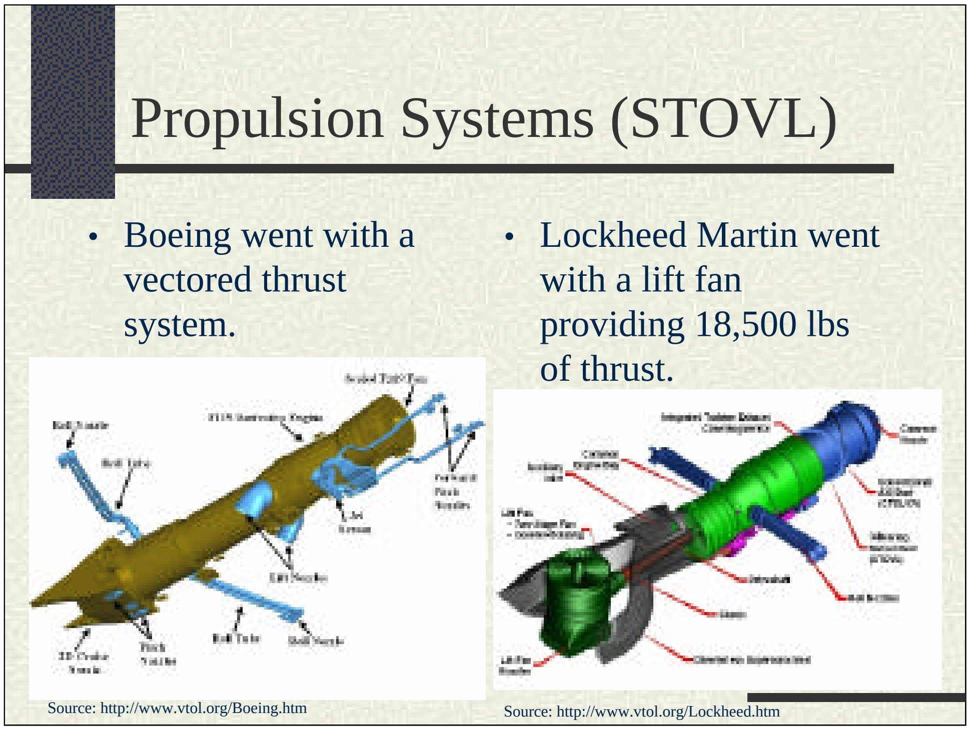
$AR = b^2/S$

-The Carrier variant has the ability to fold its wings. In the folded case, the span is in parentheses.



Lockheed's X-35

Source: www.aerospaceweb.org/aircraft/fighter/x32data.shtml



Propulsion Systems (STOVL)

- Boeing went with a vectored thrust system.
- Lockheed Martin went with a lift fan providing 18,500 lbs of thrust.

Source: http://www.vtol.org/Boeing.htm

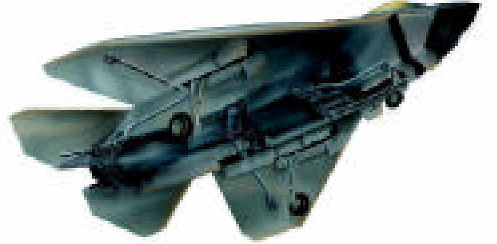
Source: http://www.vtol.org/Lockheed.htm

*The Boeing design uses a tradition approach in vector thrust. The thrust nozzles are found under the center of gravity of the aircraft. There are claims that this particular engine only brings an addition 600lbs to the variant’s weight.

*The Lockheed Design combines a lift fan along with a swivel nozzle. This is a more innovative design and designers have had less experience with this design. It claims to boost the thrust efficiency greatly but comes at a large weight penalty of about 4,000 lbs.

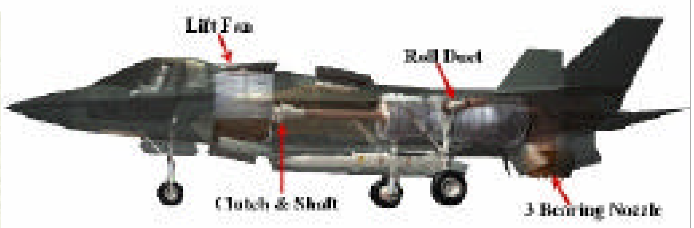
Propulsion Systems (STOVL)

Source: http://www.vtol.org/Boeing.htm

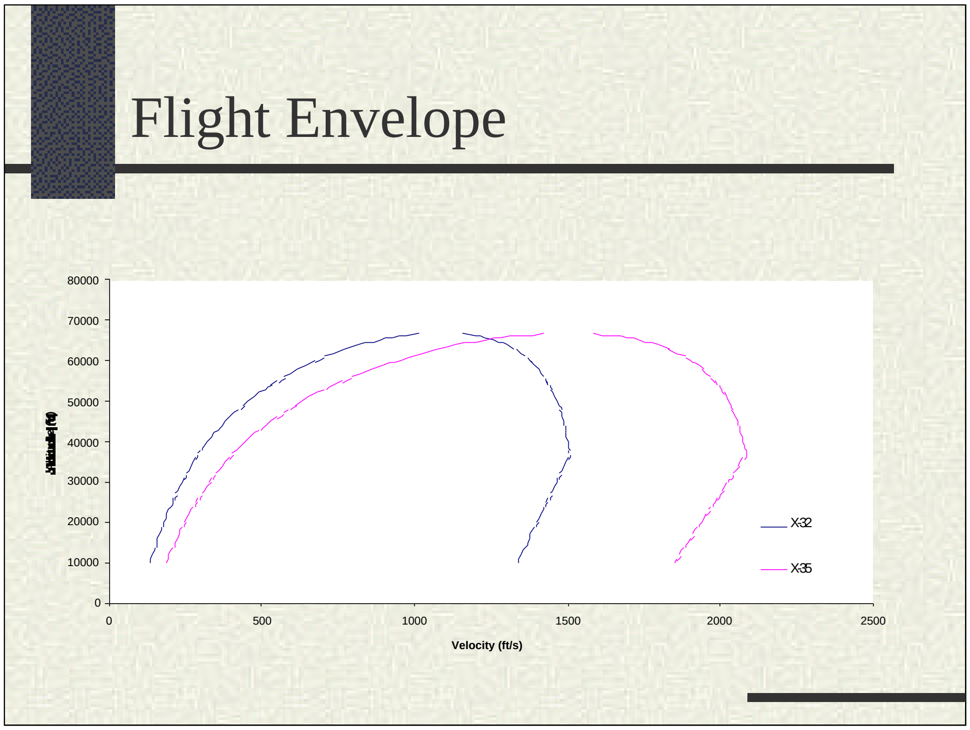


X-32

X-35



Source: http://www.vtol.org/Lockheed.htm



Flight Envelope

*This plot of the flight envelope shows that the X-35 can experience much higher speeds than the X-32 can at the same altitude during steady, level flight with a given throttle setting.

It should be noted:

-This is a plot of the flight envelope for the Boeing X-32(A) and Lockheed's X-35(A) variants.

-This flight envelope was created by looking at the intersection of the thrust required curve and thrust available curve. This resulted in:

$$V = [(T_a/S)/(\rho_{SL}\sigma C_{D0})*\{1(+/-)[1-(4KC_{D0})/(T_a/W)^2]\}^{0.5}]^{0.5} \qquad \text{-(1)}$$

Where

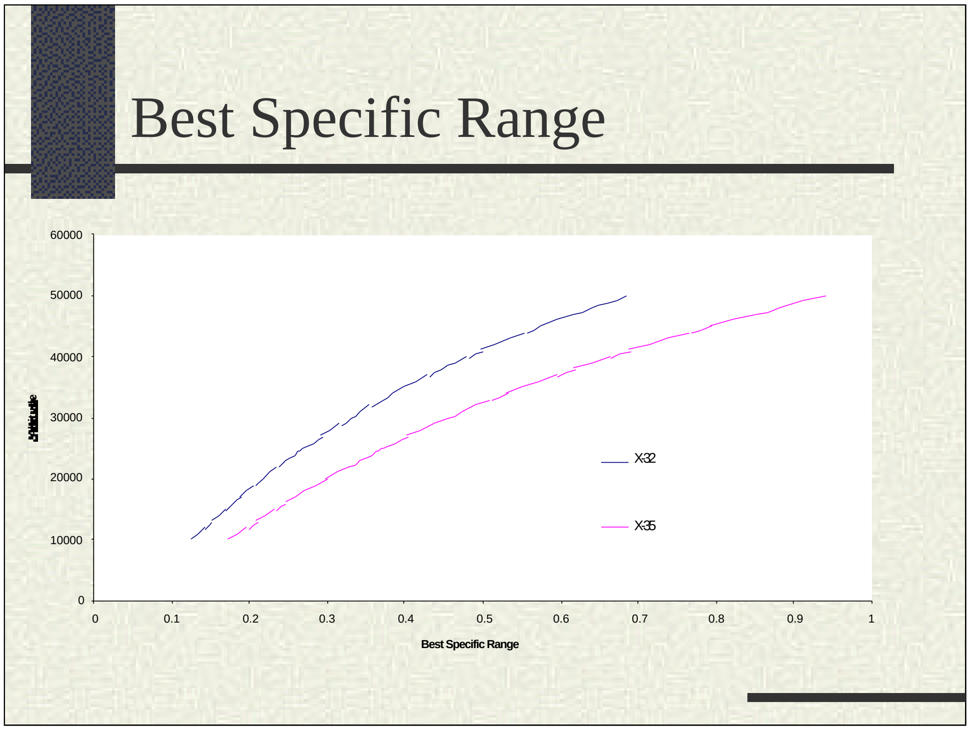
$K = 1/(\pi ARE)$

$T_a = T_{SL}\sigma^{0.7}$ for altitude < 36,000

$= 1.439\sigma T_{SL}$ for altitude > 36,000

$\sigma = \exp(-\text{altitude}/30{,}500\text{ ft})$

-This equation does not take into effect compressibility effects. Therefore the actual maximum velocity of this flight envelope can never be reached. It should also be noted, that the following performance analyses do not take into affect wave drag and compressibility. Therefore, there trends instead of their



Best Specific Range

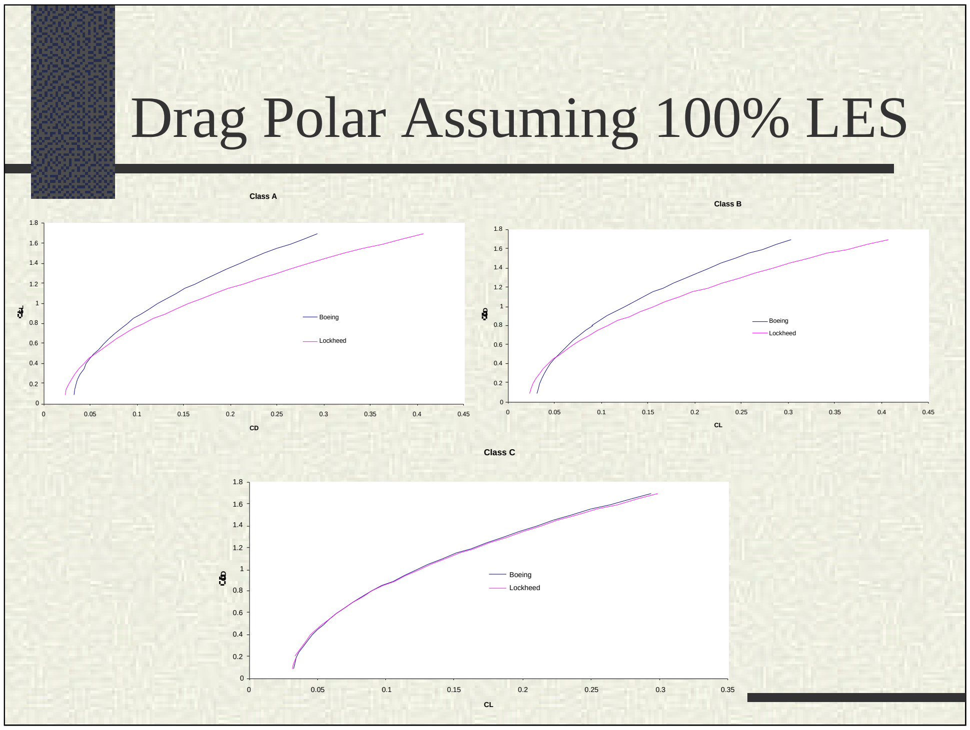
*This plot of the altitude versus Best Specific Range shows that the X-35 can experience much higher values of specific range than the X-32 can at the same altitude during steady, level flight with a given throttle setting.

It should be noted:

-The Best Range was calculated from :

$$BSR = (1.07/sfc)*\{(W/S)/\rho\}^{0.5} * \{AR*E\}^{0.25}/(C_{D0}{}^{0.75}) * (1/W)$$ - (2)

-Equation (2) was referenced from my notes.



Drag Polar Assuming 100% LES

*These are plots of drag polars, assuming 100% Leading Edge Suction, for all there variants. As can be seen in the A and B variant cases, the Boeing X-32 can achieve higher coefficients of lift at the same coefficient of drag as the X-35.

It should be noted :

-Assumptions made are as follows :

$L/D_{,max}= 9$ (value seen in most subsonic fighters)

E = 0.9

-Those assumptions allowed a CD0 to be calculated :

$$C_{D0} = (\pi ARE)/(2*{}^{L}/_{D,max})^2 \qquad -(3)$$

C_{D0} value for :

X-32A = 0.0305

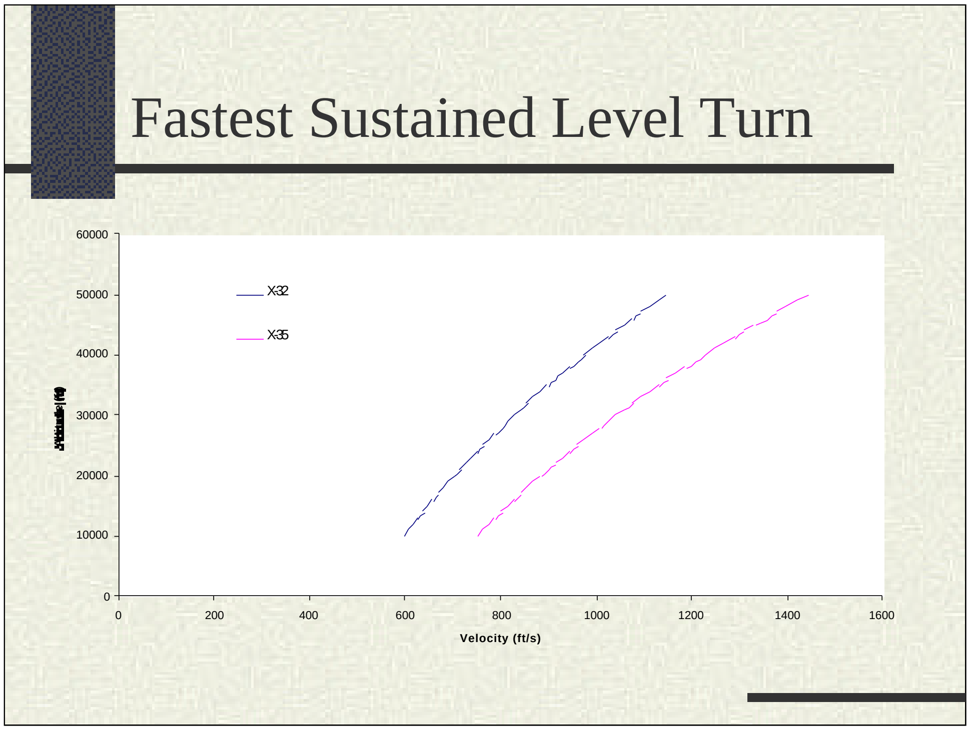
X-35A = 0.209

X-32B = 0.0294

X-35B = 0.0209

X-32C = 0.305

X-35C = 0.298



Fastest Sustained Level Turn

*This is a plot of altitude versus velocity of the fastest sustained level turn. As one can see, the X-35 experiences higher velocities at particular values of altitude in all cases versus the X-32.

It should be noted :

-The equation used to produce this plot was :

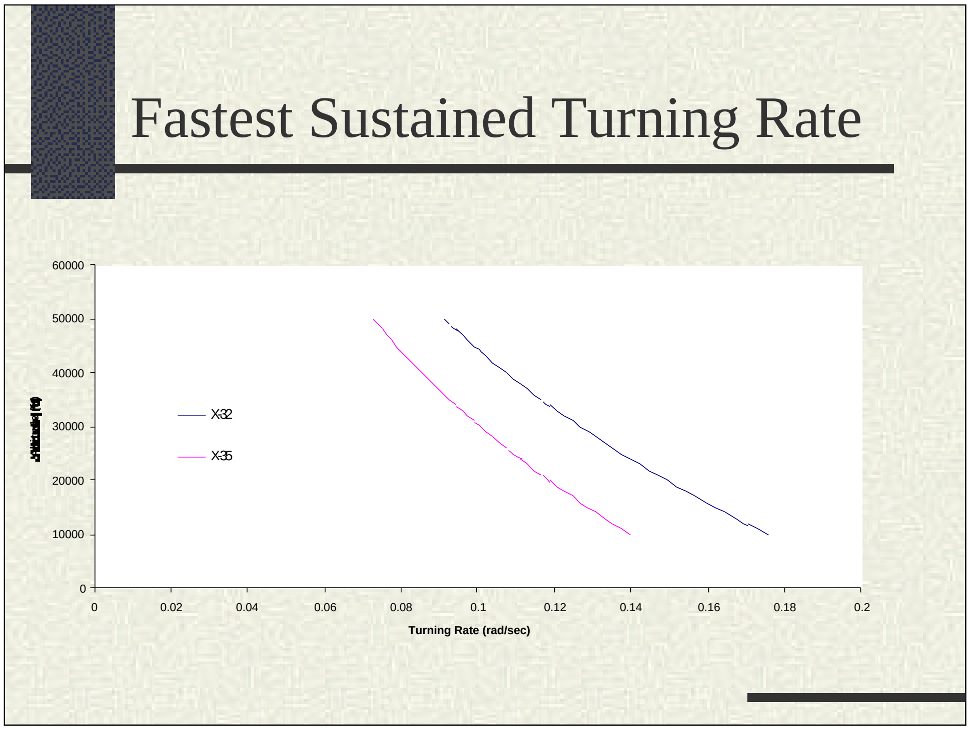
$$V_{FT} = [(2W/(S\rho_{SL}\sigma)]^{0.5} * (K/C_{D0})^{0.25} \qquad \text{-(5)}$$

It was derived by looking at the aircraft’s angular velocity, taking its derivative so it is at a maximum, substituting in the load factor for the aircraft and then solving for the velocity. The fastest turn velocity is equal to the level flight minimum drag velocity seen by the aircraft.

-Compressibility effects are again not included in the analysis.

-Equation (5) is referenced from :

Asselin, Mario An Introduction to Aircraft Performance, AIAA 1965

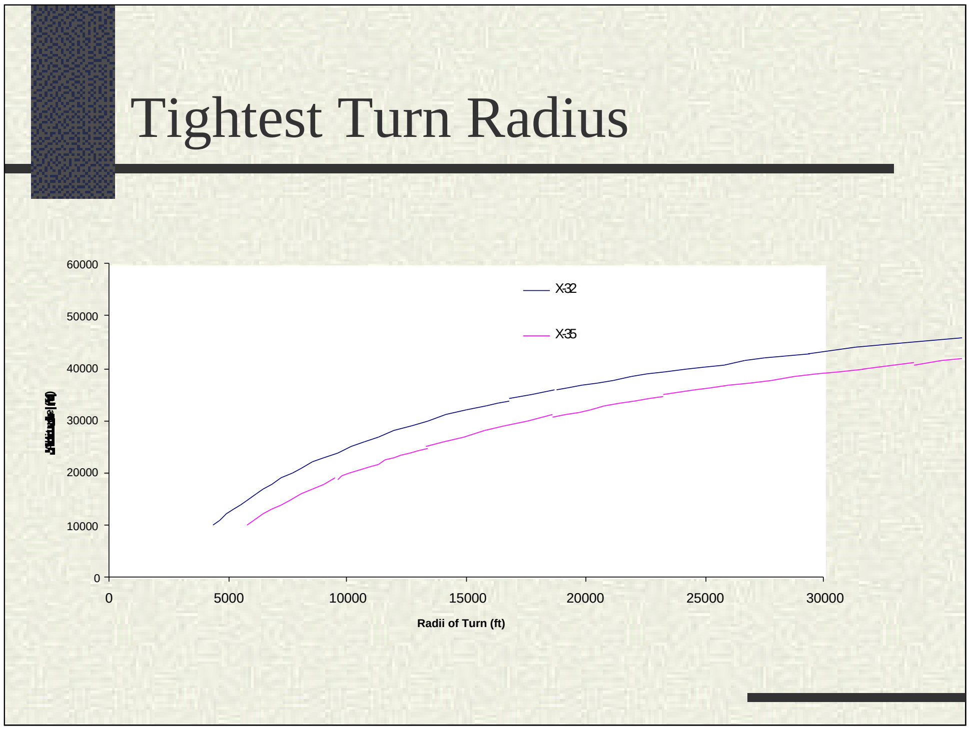


Fastest Sustained Turning Rate

*This is a plot of altitude versus sustained turning rate. As can be seen, the X-32 though not have the fastest turning velocity, does contain the fastest turning rate. This is a result of the span of the X-32 being larger than the X-35. As seen earlier in the drag polars, the X-32 is able to experience higher C_L's at the same C_D's. It is largely affected by the lower wing loading seen in the X-32.

It should be noted :

-Turning rate was calculated by taking the equation for the angular velocity of the aircraft and dividing by the fastest sustained level turn velocities.



Tightest Turn Radius

*This is a plot of altitude versus radius of turn. This plots reinforces the X-32 can indeed make sharper turns and have higher turning rates than the X-35. The plot shows that the X-35 experiences larger turning radii at the same altitude versus the X-32. It is also affected by the lower wing loading seen in the X-32. The lower wing loading allows for higher turning rates to be achieved.

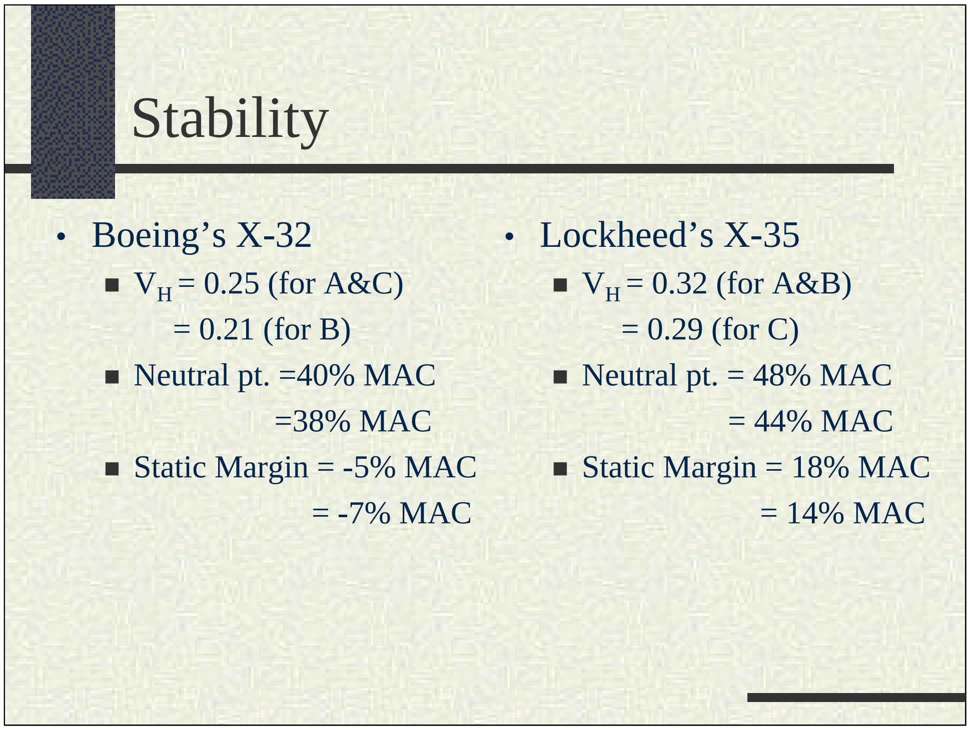
It should be noted :

-The tightest turn radius was calculated by the equation :

$$r_{TT} = [4K(^{W}/_{S})]/[\mathbf{r}_{SL}\mathbf{s}g(^{T}/_{W})(1-(1/n_{max}^{2}))^{0.5}] \quad -(6)$$

Equation (6) is referenced from :

Asselin, Mario An Introduction to Aircraft Performance, AIAA 1965



Stability

- Boeing’s X-32
  - $V_H = 0.25$ (for A&C)
    $= 0.21$ (for B)
  - Neutral pt. =40% MAC
    =38% MAC
  - Static Margin = -5% MAC
    = -7% MAC
- Lockheed’s X-35
  - $V_H = 0.32$ (for A&B)
    $= 0.29$ (for C)
  - Neutral pt. = 48% MAC
    = 44% MAC
  - Static Margin = 18% MAC
    = 14% MAC

*To begin with, the static margin values found for the X-35, are not to be trusted at all. For a fighter such as this the stability should be a negative number. It was not found to be and can be attributed to a poor schematic which was used in the measure of various locations within the X-35.

*The method used to find the static margin of the X-32 is as follows :

-First the neutral point must be found. To calculate the neutral point the following equation was used:

$h_n = h_{ac,wb} + V_H(a_t/a)(1-\mathbf{de/da})$

Where

$h_{ac,wb}$ = location of aerodynamic center of the wing (assumed to be 0.25)

de/da = change in downwash/change in angle of attack (assumed to be 0.33 for 34,000ft, Mach 0.8)

$a = dC_L/d\mathbf{a}$ (of aircraft) $= (\mathbf{p}AR)/[1+\{1+({}^{AR}/_{2\cos\mathbf{L}})^2\}]^{0.5}$

$a_t = dC_L/d\mathbf{a}$ (of aircraft tail) $= (\mathbf{p}AR)/[1+\{1+({}^{AR}/_{2\cos\mathbf{L}})^2\}]^{0.5}$

V_H = tail volume coefficient

–Once the neutral point is found, the center of gravity of the aircraft is subtracted from it and the result is the static margin.

It should be noted :

Conclusion

- In the end, I believe Boeing’s X-32 will be chosen based on its maneuverability and agility.

References

www.boeing.com

www.lmtas.com

www.aerospaceweb.org

www.answer.org

www.vtol.org

www.jast.mil/NSFrames.htm