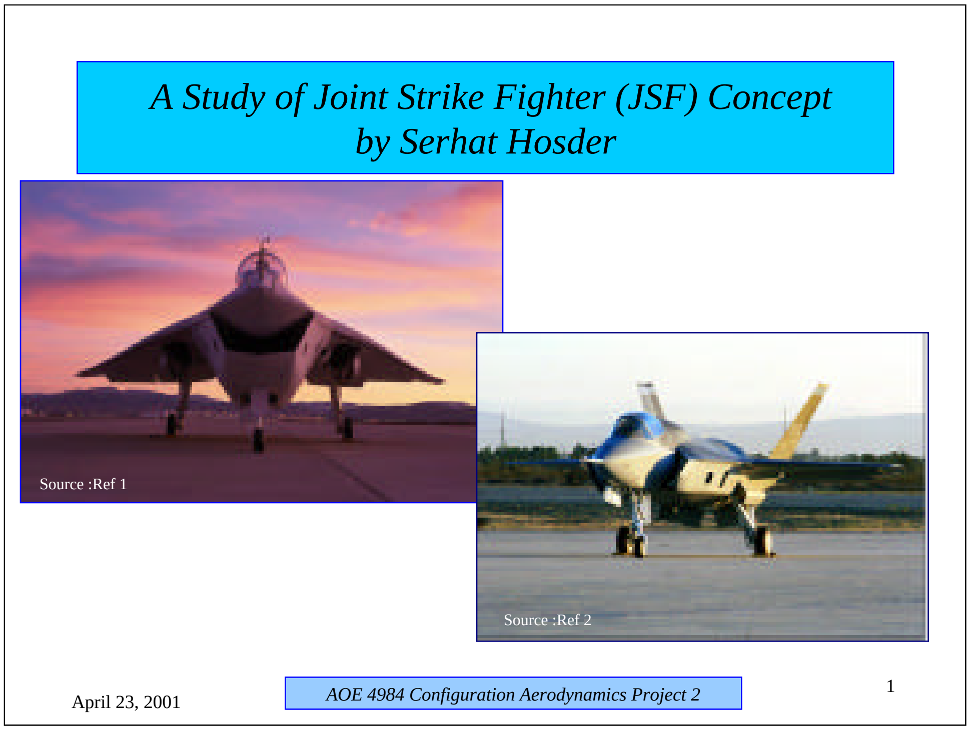

# *A Study of Joint Strike Fighter (JSF) Concept*
*by Serhat Hosder*

Source :Ref 1

Source :Ref 2

AOE 4984 Configuration Aerodynamics

Project #2

Project title: A study of Joint Strike Fighter (JSF) Cocept

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Course Instructor: Dr. W. A. Mason

Presentation Date: April 23, 2001

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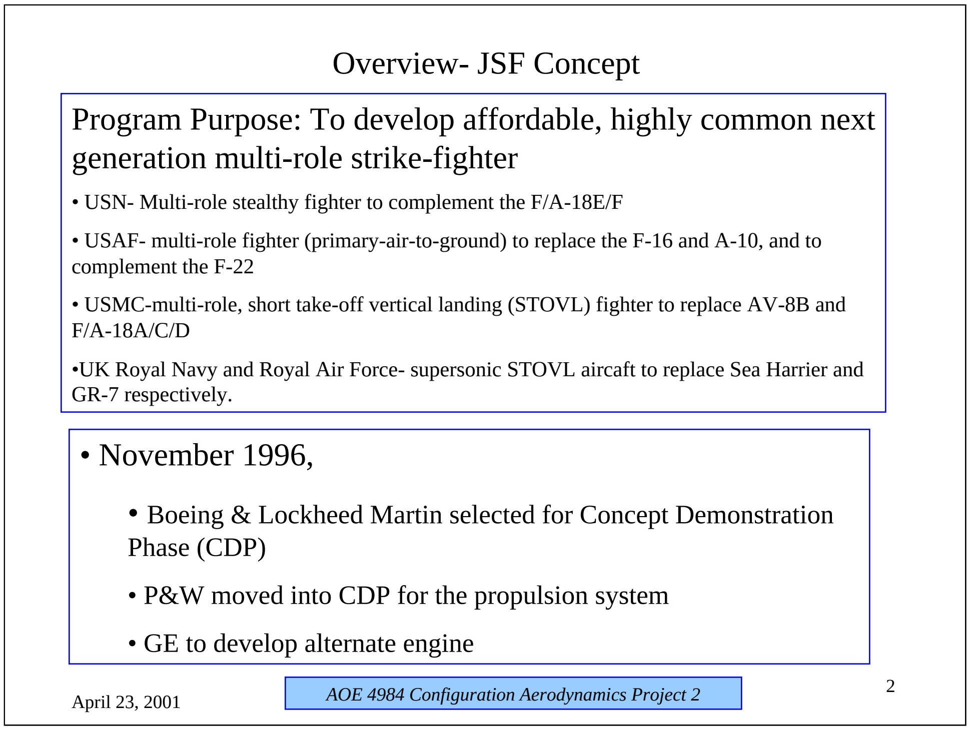

## Overview- JSF Concept

Program Purpose: To develop affordable, highly common next generation multi-role strike-fighter

- USN- Multi-role stealthy fighter to complement the F/A-18E/F
- USAF- multi-role fighter (primary-air-to-ground) to replace the F-16 and A-10, and to complement the F-22
- USMC-multi-role, short take-off vertical landing (STOVL) fighter to replace AV-8B and F/A-18A/C/D
- UK Royal Navy and Royal Air Force- supersonic STOVL aircaft to replace Sea Harrier and GR-7 respectively.

- November 1996,
  - Boeing & Lockheed Martin selected for Concept Demonstration Phase (CDP)
  - P&W moved into CDP for the propulsion system
  - GE to develop alternate engine

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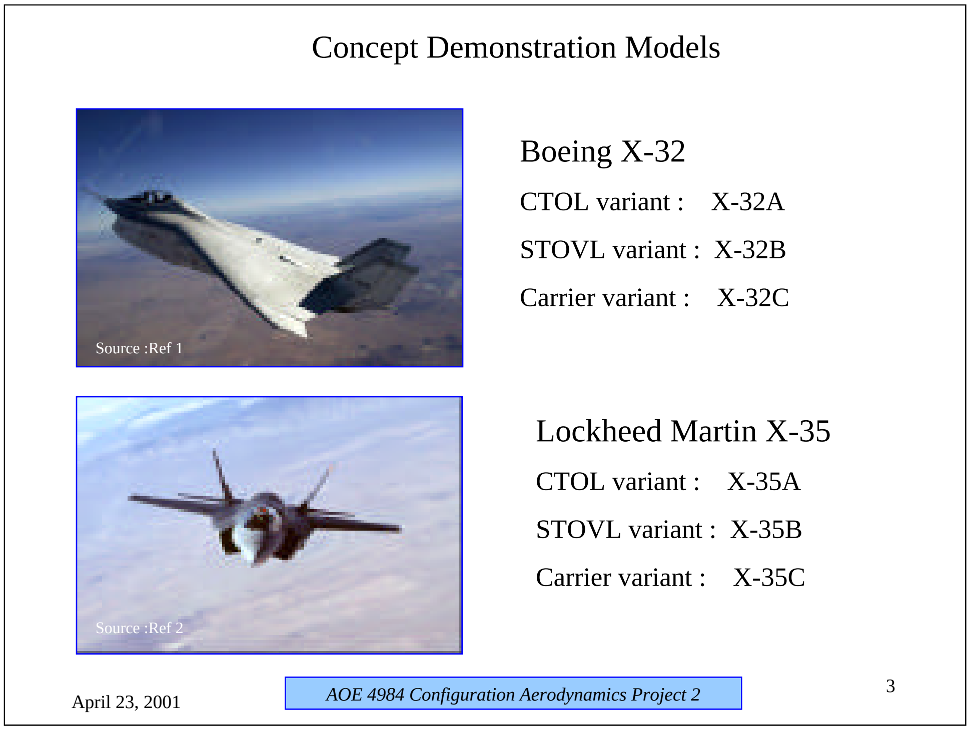
- The Joint Strike Fighter (JSF) program will develop and field an affordable, highly common family of next generation multi-role strike fighter aircraft for the Navy, Air Force, Marine Corps and allies (Ref 6). With the start of the service of the JSF approximately in 2008, some of today’s fighters like F-16, F/A-18A/C/D would be replaced and the mission load of advanced fighters like F-22 would be shared.

- Affordability, reliability, commonalty, and the use of advanced technology are the key factors that shape the purpose of the JSF program.

- One of the important goals of the JSF program is to develop the first supersonic STOVL.

- The JSF program began in 1994 as the Joint Advanced Strike Technology (JAST) program. Initially four contractors were involved: Boeing, Lockheed, McDonnell Douglas/British Aerospace and Northtrop. On 16 November 1996, the Secretary of Defense announced that Boeing and Lockheed Martin would continue into the Concept Demonstration Phase (CDP). Pratt and Whitney (P&W) also moved forward into CDP to develop the propulsion system (Ref 6).
- Although the dates are not certain, the winning team for the CDP phase is expected to be announced in late 2001 and the selected JSF to be in service in around 2008.



## Concept Demonstration Models

Source :Ref 1

### Boeing X-32

CTOL variant : X-32A

STOVL variant : X-32B

Carrier variant : X-32C

Source :Ref 2

### Lockheed Martin X-35

CTOL variant : X-35A

STOVL variant : X-35B

Carrier variant : X-35C

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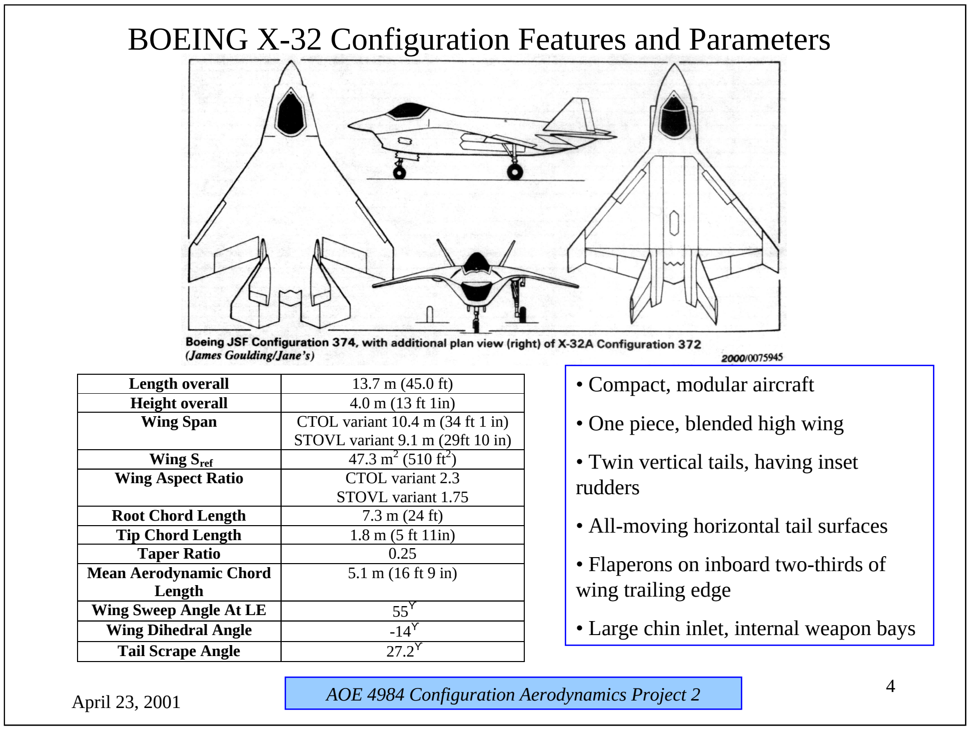
1st flight of X-32A: September 18, 2000

1st flight of X-32B: March 29, 2001

1st flight of X-35A: October 21, 2000



## BOEING X-32 Configuration Features and Parameters

**Boeing JSF Configuration 374, with additional plan view (right) of X-32A Configuration 372**
*(James Goulding/Jane's)*
2000/0075945

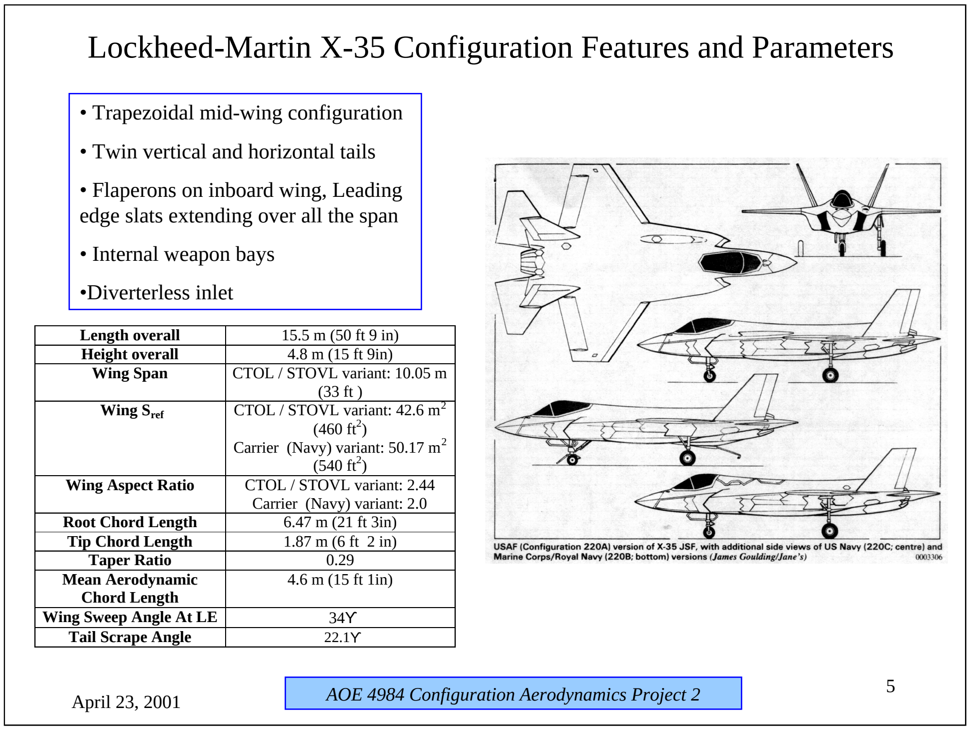
| | |
|---|---|
| **Length overall** | 13.7 m (45.0 ft) |
| **Height overall** | 4.0 m (13 ft 1in) |
| **Wing Span** | CTOL variant 10.4 m (34 ft 1 in)<br>STOVL variant 9.1 m (29ft 10 in) |
| **Wing $S_{ref}$** | 47.3 $m^2$ (510 $ft^2$) |
| **Wing Aspect Ratio** | CTOL variant 2.3<br>STOVL variant 1.75 |
| **Root Chord Length** | 7.3 m (24 ft) |
| **Tip Chord Length** | 1.8 m (5 ft 11in) |
| **Taper Ratio** | 0.25 |
| **Mean Aerodynamic Chord Length** | 5.1 m (16 ft 9 in) |
| **Wing Sweep Angle At LE** | $55^{Y}$ |
| **Wing Dihedral Angle** | $-14^{Y}$ |
| **Tail Scrape Angle** | $27.2^{Y}$ |

- Compact, modular aircraft
- One piece, blended high wing
- Twin vertical tails, having inset rudders
- All-moving horizontal tail surfaces
- Flaperons on inboard two-thirds of wing trailing edge
- Large chin inlet, internal weapon bays

All the wing geometric parameters (except overall length, height and wing span) and the tail scrape angle are determined from the layout pictures. Therefore, the values are approximate. All wing parameters like taper ratio and mean aerodynamic chord are based on trapezoidal wing assumption.

The basic design features of Boeing X-32 can be summarized as (ref 8):

- Compact, modular aircraft
- One piece, blended high wing
- Twin vertical tails, having inset rudders
- All-moving horizontal tail surfaces
- Flaperons on inboard two-thirds of wing trailing edge
- Large chin inlet, internal weapon bays



## Lockheed-Martin X-35 Configuration Features and Parameters

- Trapezoidal mid-wing configuration
- Twin vertical and horizontal tails
- Flaperons on inboard wing, Leading edge slats extending over all the span
- Internal weapon bays
- Diverterless inlet

| | |
|---|---|
| **Length overall** | 15.5 m (50 ft 9 in) |
| **Height overall** | 4.8 m (15 ft 9in) |
| **Wing Span** | CTOL / STOVL variant: 10.05 m (33 ft ) |
| **Wing $S_{ref}$** | CTOL / STOVL variant: 42.6 $m^2$ (460 $ft^2$)<br>Carrier (Navy) variant: 50.17 $m^2$ (540 $ft^2$) |
| **Wing Aspect Ratio** | CTOL / STOVL variant: 2.44<br>Carrier (Navy) variant: 2.0 |
| **Root Chord Length** | 6.47 m (21 ft 3in) |
| **Tip Chord Length** | 1.87 m (6 ft 2 in) |
| **Taper Ratio** | 0.29 |
| **Mean Aerodynamic Chord Length** | 4.6 m (15 ft 1in) |
| **Wing Sweep Angle At LE** | 34ϒ |
| **Tail Scrape Angle** | 22.1ϒ |

**USAF (Configuration 220A) version of X-35 JSF, with additional side views of US Navy (220C; centre) and Marine Corps/Royal Navy (220B; bottom) versions** *(James Goulding/Jane's)* 0003306

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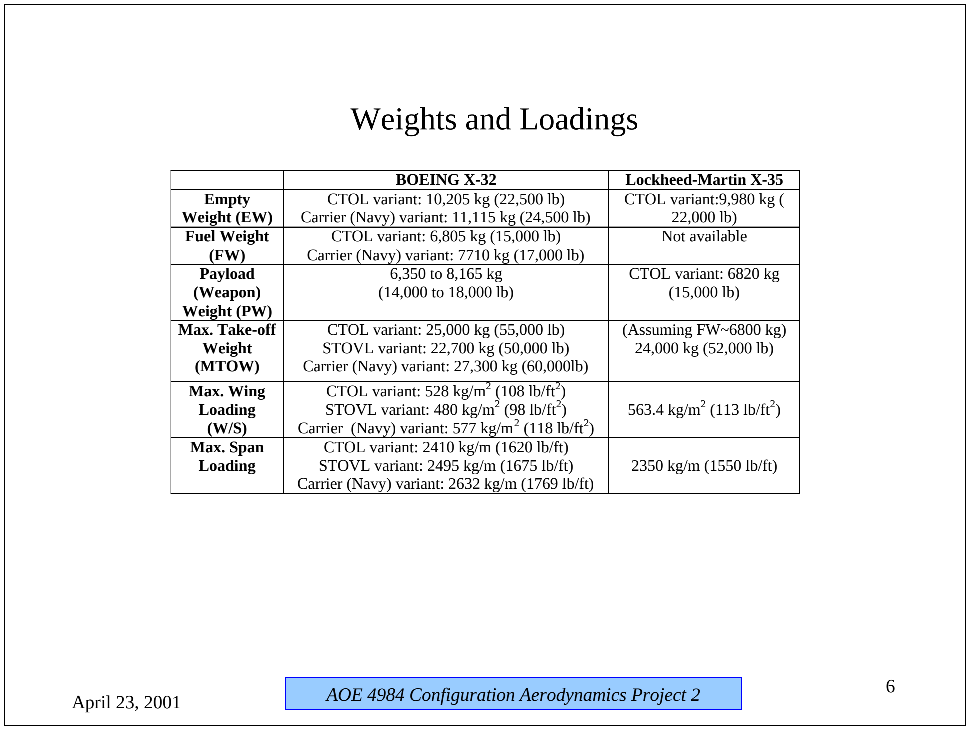
All the wing geometric parameters (except overall length, height and wing span) and the tail scrape angle are determined from the layout pictures. Therefore, the values are approximate. All wing parameters like taper ratio and mean aerodynamic chord are based on trapezoidal wing assumption.

Some of the aerodynamic design features of X-35 can be summarized as:

- Trapezoidal mid-wing configuration
- Twin vertical and horizontal tails
- Flaperons on inboard wing, Leading edge slats extending over all the span
- Internal weapon bays
- Diverterless inlet

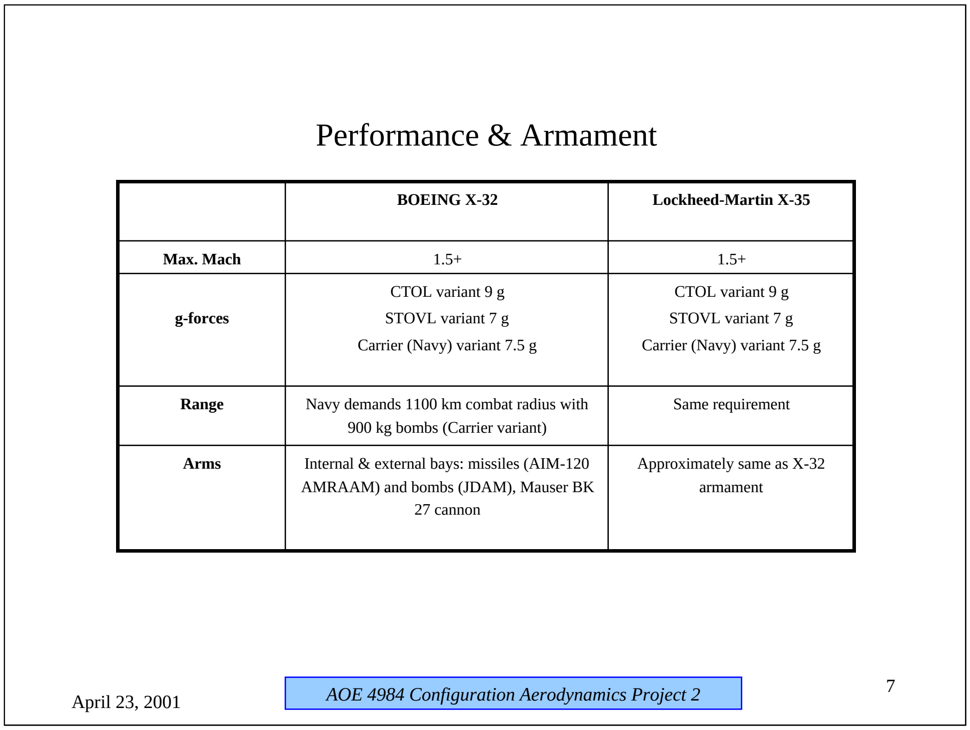


## Weights and Loadings

| | BOEING X-32 | Lockheed-Martin X-35 |
|---|---|---|
| **Empty Weight (EW)** | CTOL variant: 10,205 kg (22,500 lb)<br>Carrier (Navy) variant: 11,115 kg (24,500 lb) | CTOL variant:9,980 kg ( 22,000 lb) |
| **Fuel Weight (FW)** | CTOL variant: 6,805 kg (15,000 lb)<br>Carrier (Navy) variant: 7710 kg (17,000 lb) | Not available |
| **Payload (Weapon) Weight (PW)** | 6,350 to 8,165 kg (14,000 to 18,000 lb) | CTOL variant: 6820 kg (15,000 lb) |
| **Max. Take-off Weight (MTOW)** | CTOL variant: 25,000 kg (55,000 lb)<br>STOVL variant: 22,700 kg (50,000 lb)<br>Carrier (Navy) variant: 27,300 kg (60,000lb) | (Assuming FW~6800 kg)<br>24,000 kg (52,000 lb) |
| **Max. Wing Loading (W/S)** | CTOL variant: 528 kg/m$^2$ (108 lb/ft$^2$)<br>STOVL variant: 480 kg/m$^2$ (98 lb/ft$^2$)<br>Carrier (Navy) variant: 577 kg/m$^2$ (118 lb/ft$^2$) | 563.4 kg/m$^2$ (113 lb/ft$^2$) |
| **Max. Span Loading** | CTOL variant: 2410 kg/m (1620 lb/ft)<br>STOVL variant: 2495 kg/m (1675 lb/ft)<br>Carrier (Navy) variant: 2632 kg/m (1769 lb/ft) | 2350 kg/m (1550 lb/ft) |

Since both models are in development phase, the certain values of the weight components for each aircraft are not available. There are slight differences between the info obtained from different sources. However, above values can give an approximate idea of the distribution of the overall aircraft weight for each model and variant.

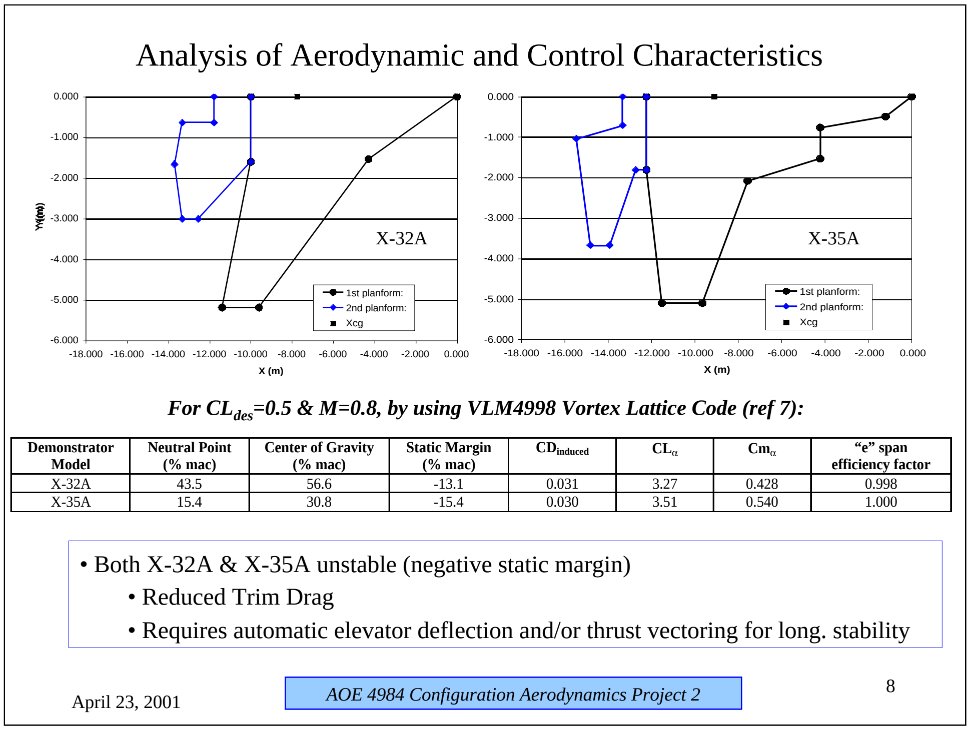
Above table shows that the CTOL variant of both X-32 and X-35 have approximately the same EW, FW, PW and MTOW. Although there is slight difference between the wing and span loadings due to the wing ref. area and the span for each CTOL variant, these values are still comparable. Since the induced drag is directly proportional with the span loading, this value for the two CTOL variant will be the approximately the same for the same flight dynamic pressure.



## Performance & Armament

| | BOEING X-32 | Lockheed-Martin X-35 |
|---|---|---|
| **Max. Mach** | 1.5+ | 1.5+ |
| **g-forces** | CTOL variant 9 g<br>STOVL variant 7 g<br>Carrier (Navy) variant 7.5 g | CTOL variant 9 g<br>STOVL variant 7 g<br>Carrier (Navy) variant 7.5 g |
| **Range** | Navy demands 1100 km combat radius with 900 kg bombs (Carrier variant) | Same requirement |
| **Arms** | Internal & external bays: missiles (AIM-120 AMRAAM) and bombs (JDAM), Mauser BK 27 cannon | Approximately same as X-32 armament |

As for the weights and loading, the precise values for the performance parameters are not available. However, most of these parameters are the requirements set by the JSF program and both models should satisfy these requirements.



## Analysis of Aerodynamic and Control Characteristics

*For $CL_{des}$=0.5 & M=0.8, by using VLM4998 Vortex Lattice Code (ref 7):*

| Demonstrator Model | Neutral Point (% mac) | Center of Gravity (% mac) | Static Margin (% mac) | $CD_{induced}$ | $CL_{\alpha}$ | $Cm_{\alpha}$ | "e" span efficiency factor |
|---|---|---|---|---|---|---|---|
| X-32A | 43.5 | 56.6 | -13.1 | 0.031 | 3.27 | 0.428 | 0.998 |
| X-35A | 15.4 | 30.8 | -15.4 | 0.030 | 3.51 | 0.540 | 1.000 |

- Both X-32A & X-35A unstable (negative static margin)
  - Reduced Trim Drag
  - Requires automatic elevator deflection and/or thrust vectoring for long. stability

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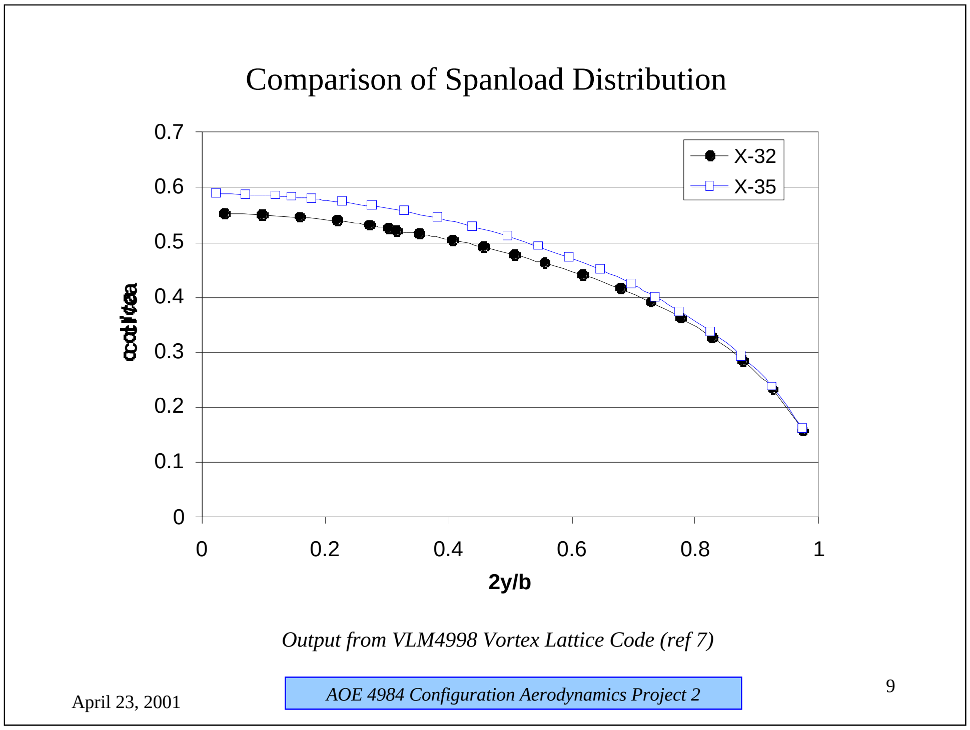
VLM4998 vortex lattice method (ref 7) has been used to find the static margin and the span loading for each aircraft. The plan forms of X-32 and X-35 have been modeled as shown in the slide. For a design CL of 0.5 and M=0.8, the static margin of both aircraft were found to be negative which indicates unstable configurations. However these values are in typical limits of today's most modern fighters (F-16). The determination of the static margin depends strongly on the location of the c.g of the aircraft. The c.g of each configuration were determined from the layouts by using the landing gear position. Therefore any error originated from the c.g determination would also effect the value of the static margin value.

Note that the planform graphs are not in the same scale.



Comparison of Spanload Distribution

*Output from VLM4998 Vortex Lattice Code (ref 7)*

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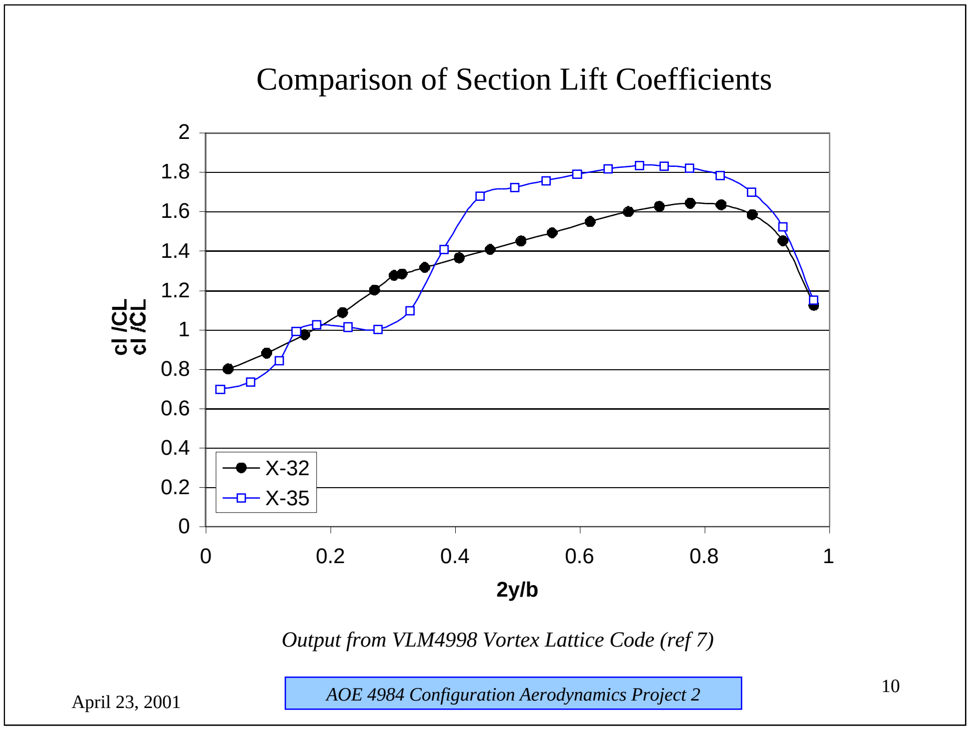
Although the difference is not big, X-35 has slightly higher span load distribution. In the figure shown in the slide:

c: local chord length

ca: average chord length (here it’s taken as mean aerodynamic chord)

cl: local lift coefficient



Comparison of Section Lift Coefficients

*Output from VLM4998 Vortex Lattice Code (ref 7)*

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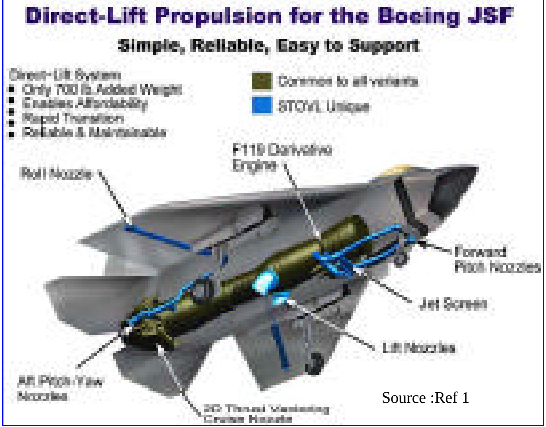
Max. cl for X-32 is approximately at 0.75 of the half span, while this value is located at 0.70 of the half span for X-35. In both cases, max. cl location is more outward than the control surfaces (flaperons) on the wing, so in case of stall in these locations, control surface would not be effected and the control of the aircraft could be maintained.

# Boeing X-32 Propulsion System

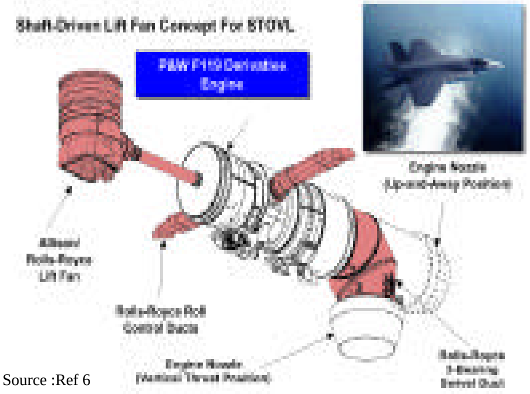


Source :Ref 1

April 16 2001, X-32B successfully completed its first in-flight conversions — from conventional to short-takeoff-and-vertical landing (STOVL) flight mode and back again. (Ref 1)

- Direct Lift Concept for STOVL
- Installed on the Boeing JSF X-32B CD Aircraft
- P&W JSF119-PW-614 low-bypass Turbofan Engine (40,000+ lb-thrust class)
- Rolls-Royce responsible for design, testing and development of lift system and spool duct.
- Primary vertical lift from lift nozzles, located near c.g of aircraft
- Moving parts minimized
- Increased reliability and maintainability, reduced cost

# Lockheed-Martin X-35 Propulsion System



Source :Ref 6

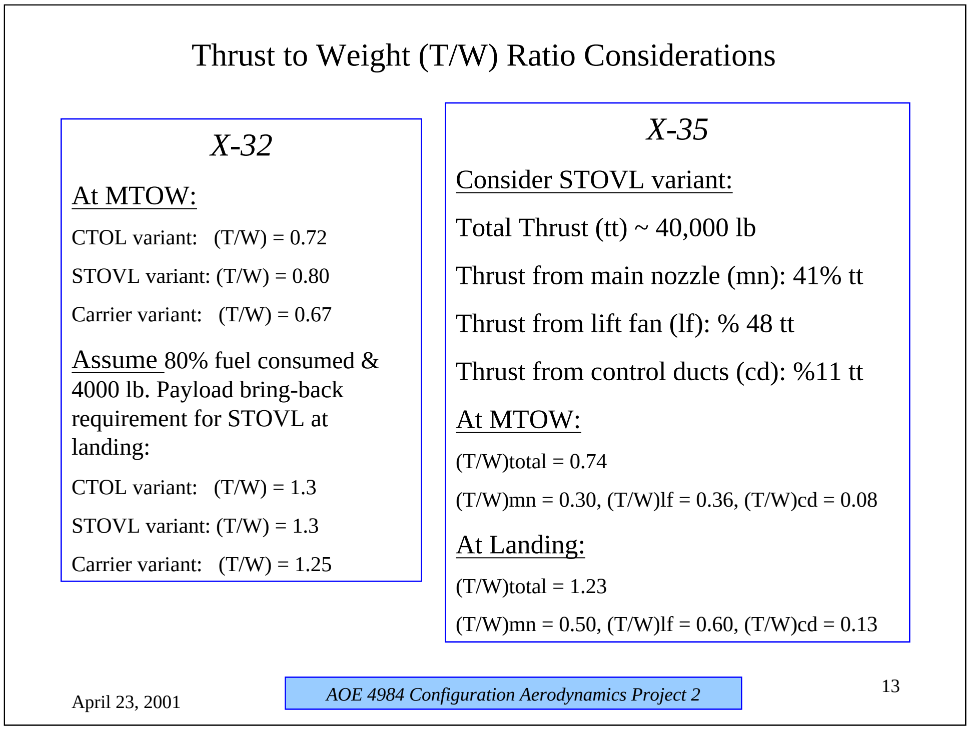
•Vertically oriented Lift Fan for STOVL concept

• P&W JSF119-PW-611 low-bypass Turbofan Engine (40,000+ lb-thrust class)

•Two-stage low pressure turbine drives the shaft through a clutch system

•Significant amount of thrust augmentation from the lift fan (~18,000 lb)

•Lower exhaust jet temperature and pressure, more benign ground environment during hover compared to direct lift



## Thrust to Weight (T/W) Ratio Considerations

### *X-32*

At MTOW:

CTOL variant: (T/W) = 0.72

STOVL variant: (T/W) = 0.80

Carrier variant: (T/W) = 0.67

Assume 80% fuel consumed & 4000 lb. Payload bring-back requirement for STOVL at landing:

CTOL variant: (T/W) = 1.3

STOVL variant: (T/W) = 1.3

Carrier variant: (T/W) = 1.25

### *X-35*

Consider STOVL variant:

Total Thrust (tt) ~ 40,000 lb

Thrust from main nozzle (mn): 41% tt

Thrust from lift fan (lf): % 48 tt

Thrust from control ducts (cd): %11 tt

At MTOW:

$(T/W)_{total} = 0.74$

$(T/W)_{mn} = 0.30$, $(T/W)_{lf} = 0.36$, $(T/W)_{cd} = 0.08$

At Landing:

$(T/W)_{total} = 1.23$

$(T/W)_{mn} = 0.50$, $(T/W)_{lf} = 0.60$, $(T/W)_{cd} = 0.13$

Max. Thrust (sea level, static) value for each aircraft is approximately 40,000 lb. The values of (T/W) landing configuration (weight) imply that the vertical landing could be achieved safely.

# Conclusions

- X-32 and X-35 have different aerodynamic configurations
- Requirements and performance parameters set by JSF program
- Key factor in the selection procedure STOVL performance
    - Demonstration of a reliable, proven, efficient and affordable lift system for STOVL would determine the winner

# References

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8. 2000-2001 Jane’s All The World’s Aircraft