Analysis of JSF Prototypes

By: Timothy D. Collins

Photo from: *http://www.popsci.com/scitech/features/xplane/index.html*

Boeing X-32 on Left, and Lockheed-Martin X-35 on Right.

These two aircraft are designed to compete for the JSF production run.

Background Information

- Joint Strike Fighter is a multi-role, multi-national Aircraft
- STOVL capability
  - USMC
  - UK RAF
  - UK Royal Navy
- CTOL capability
  - USN
  - USAF

The JSF is to be designed for different purposes for each of the services that are involved. The services and their needs are outlined below.

US Navy: Multirole stealthy strike-fighter to complement the F/A-18E/F

US Air Force: Multi-role air to ground fighter to replace the F-16 and A-10 and to complement the F-22.

US Marine Corps: Multi- role, short takeoff, vertical landing strike fighter to replace the AV- 8B and F/A-18C/D

UK Royal Navy and Royal Air Force: Supersonic STOVL replacement for the Sea Harrier and GR- 7

Two Contractors (5 prototypes?)

- **Lockheed Martin (X-35)**
  - X-35A CTOL
    - USAF
  - X-35B STOVL
    - Reconfigured X-35A
      - USMC
      - RAF
      - RN
  - X-35C CTOL
    - USN
- **Boeing (X-32)**
  - X-32A CTOL
    - USAF
    - USN
  - X-32B STOVL
    - USMC
    - RAF
    - RN

The X-35B is the X-35A demonstrator with a lift-fan installed for vertical and short takeoff and landing.

The X-35C is a larger plane than the X-35A/B and has a lower conventional landing speed and a higher $CL_{max.}$

Characteristics (X-32)

- CTOL (A)
  - Swing: 565 ft^2
  - Span: 36 ft
  - Length: 47 ft
- STOVL (B)
  - Swing: 504 ft^2
  - Span: 30 ft
  - Length: 46 ft
- AR
  - CTOL: 2.294
  - STOVL: 1.786
- Engine
  - CTOL: JSF119-614C
  - STOVL: JSF119-614S
- TOGW
  - Proprietary (58,000 lb est.)
    - 20,000 lb – fuel
    - 20,000 lb – empty
    - 18,000 lb – weapons

AR = (b^2)/S

“S” from Aviation Week and Space Technology Source Book 2001

“engines” from Jane’s All the World’s Aircraft 2000-2001

Engines manufactured by Pratt & Whitney

Weight information

Fuel weight from http://www.popsci.com/scitech/features/xplane/xplane_2.html

Empty and weapons weight from Jane’s All the World’s Aircraft 2000-2001

Photo from: *http://www.boeing.com/defense-space/military/jsf/images/dsc_0010.htm*

This design uses side bomb bay doors to avoid radar detection when bomb bay is opened. One door at a time can be opened to the opposite side of enemy radar.

Stability of X-32

- MAC
  - 16.11 ft
- Neutral Point
  - 24.9 ft from nose
  - Static Margin
    - -14.2%
  - Unstable

Photo from: *http://www.popsci.com/scitech/features/xplane/xplane_2.html*

Neutral point found from VLM PC program.

Static margin of –14.2%, meaning that this plane is 14.2% unstable and must be controlled by a computerized feedback control system.

STOVL Capability (X-32B)

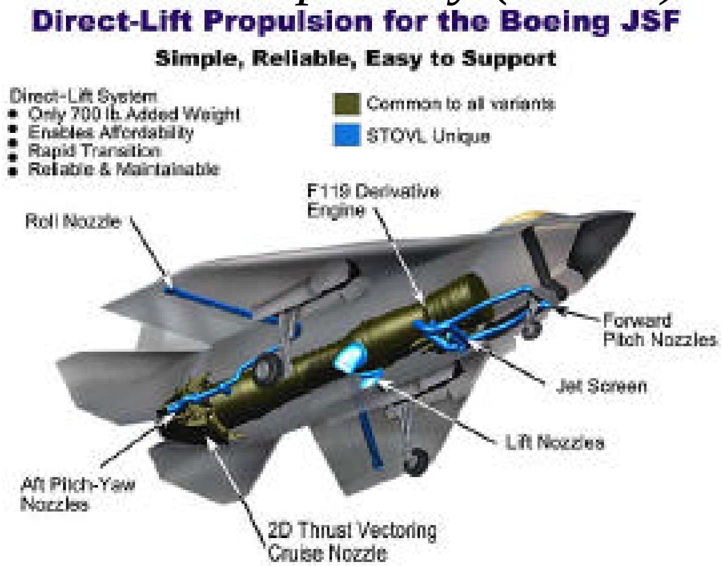


Photo from: *http://www.boeing.com/defense-space/military/jsf/images/STOVL_directLift.jpg*

STOVL Capability (X-32B) Cont.

- Direct Lift System
  - Over CG
- Lift nozzles at CG
- Control nozzles at wings, and front and aft of aircraft
- Pratt & Whitney software control system for low speed control

The Boeing design uses the direct lift system so the engine must be forward of the CG which causes many problems for weapons bay design as well as for fuel volume.

This design uses doors to direct the flow from the engine out the correct nozzles for lift or for control in the hovering and vertical landing modes. The control of the aircraft at these low speeds is accomplished with a complicated computer control developed by Pratt & Whitney.

Characteristics (X-35)

- X-35 A/B
  - Swing: 460 ft^2
  - Span: 35 ft
  - Length: 50.5 ft
- X-35 C
  - Swing: 620 ft^2
  - Span: 43 ft
  - Length: 50.8 ft
- Thrust
  - 40,000 lb
- AR
  - X-35A: 2.663
  - X-35B: 2.663
  - X-35C: 2.982
- Engine
  - CTOL: JSF119-611C
  - STOVL: JSF119-611
    - With shaft driven lift-fan
- TOGW Approximate
  - 60,000 lbs.

AR = (b^2)/S

"S" from Aviation Week and Space Technology Source Book 2001

"engines" from Jane's All the World's Aircraft 2000-2001

Engines manufactured by Pratt & Whitney

Lift-Fan manufactured by Rolls-Royce

Thrust rating from Aviation Week and Space Technology Feb. 12, 2001

Photo from:
http://www.lmaeronautics.com/image_gallery/pr_photos/jsfpr_photos/jsf_1stflight/X350269.html

Stability of X-35 A

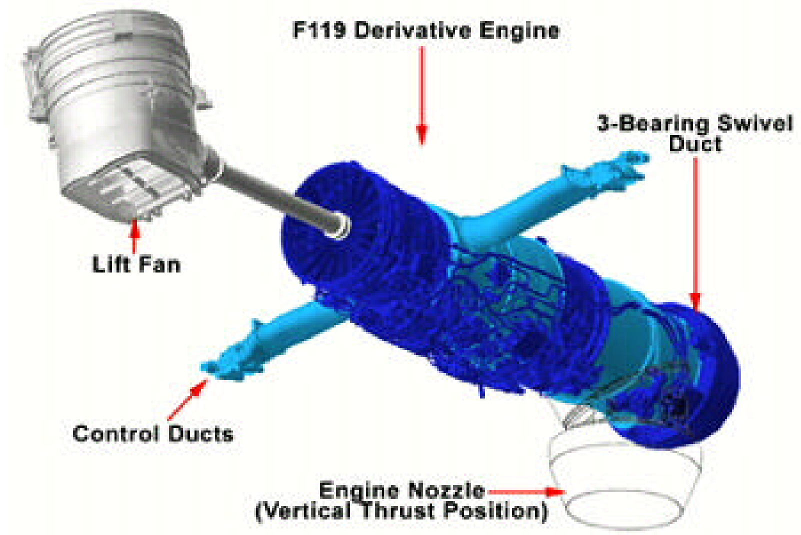
- MAC
  - 15 ft
- Neutral Point
  - 28 ft from nose
  - Static Margin
    - -25%
  - Unstable

Photo from:
http://www.popsci.com/scitech/features/xplane/xplane_3.html

Neutral point found from VLM PC program.

Static margin of -25%, meaning that this plane is 25% unstable and must be controlled by a computerized feedback control system.

STOVL Capability (X-35B)



Picture from: *http://www.fas.org/man/dod-101/sys/ac/jsf.html*

3-D vectoring nozzle produces lift as well as pitch and yaw motion at low speeds.

The roll-control ducts are used to create rolling moments in hovering flight.

The lift fan produces the majority of vertical thrust for the Lockheed JSF.

STOVL Capability (X-35B) Cont.

- Rolls-Royce Lift Fan
  - Shaft driven with clutch transfers 27,000 Hp
  - Keeps hot exhaust from engine intake
- Lift : 37,000 lbs total thrust
  - Main swivel-duct nozzle = 15,000 lbs thrust
  - Lift-Fan = 18,000 lbs thrust
  - Reaction Control Valves = 4,000 lbs thrust
- Location of Lift-Fan
  - Behind cockpit over CG

Lift fan clutch transfers over 27,000 hp to the lift fan from the engine shaft, the same amount of power as the prop shaft of an Aegis Cruiser.

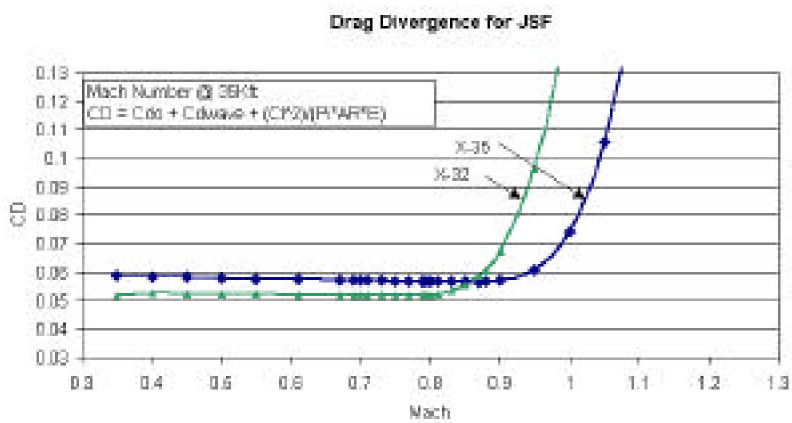
This design with the lift fan instead of a direct lift system assures that cool air is directed to the ground to produce the lift needed to hover and maneuver at low altitudes so that the ground is not damaged by hot gasses and also so that the engine does not ingest hot air which would cause a loss of thrust.

The reaction control valves and the 3-D nozzle are operated by the software developed by Pratt & Whitney and they control roll of the aircraft as well as the pitch of the aircraft.

The 3-D nozzle at the rear also aids in lift for vertical takeoff and landing conditions.

The lift fan allows the bulk of the engine to be aft of the CG while allowing most of the lift to be produced through the CG. This allows for easier design of the weapons bay and for added fuel volume over conventional systems that use a forward mounted engine with exhaust over the CG.

DRAG



MDD body for X-32 from Raymer *Aircraft Design: A Conceptual Approach*, figure 12.30

CD0 found from Mason's *friction.f* code.

Other interesting information

- Now both the manufacturers have designs that are within 5% of production designs.
- My prediction
  - Lockheed
  - My choice would be to use a combined effort
    - Side bombays
    - Lift fan

QUESTIONS?

References: