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STOVL Propulsion

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facilitated by the

FSU Fluid Mechanics Research Laboratory

Today's agenda

- STOVL Propulsion
  - What, why, who and how
  - Examples of STOVL use
  - Problems associated with STOVL use
  - Future of STOVL
- Research Aspect
  - Research Facilities
  - Sample findings

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What is STOVL?

- Short Take-off and Vertical Landing
- Mainly used in military vehicles
- Currently only on the AV-8 Harrier
- Also used on lunar and interplanetary vehicles

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Why STOVL?

- Conventional Take-off requires large amounts of capital in land to operate
- Vertical Take-offs negate an enemies benefit in bombing or destroying runways
- Possible to use in urban or unsettled areas

Kansai International Airport

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Who uses STOVL?

- US Marine Corps & Navy
- British Royal Air Force and Navy
- NASA (spacecraft)
- Harrier is built on 60's technology

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AV-8 Harrier

- AV-8B is one of the most flexible military air platforms to date
- Originally a British prototype aircraft, the Kestrel, which first flew in October, 1960

How does STOVL work?

- A portion of the engine’s thrust is vectored downward, via nozzles, producing thrust

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Vertical Takeoff

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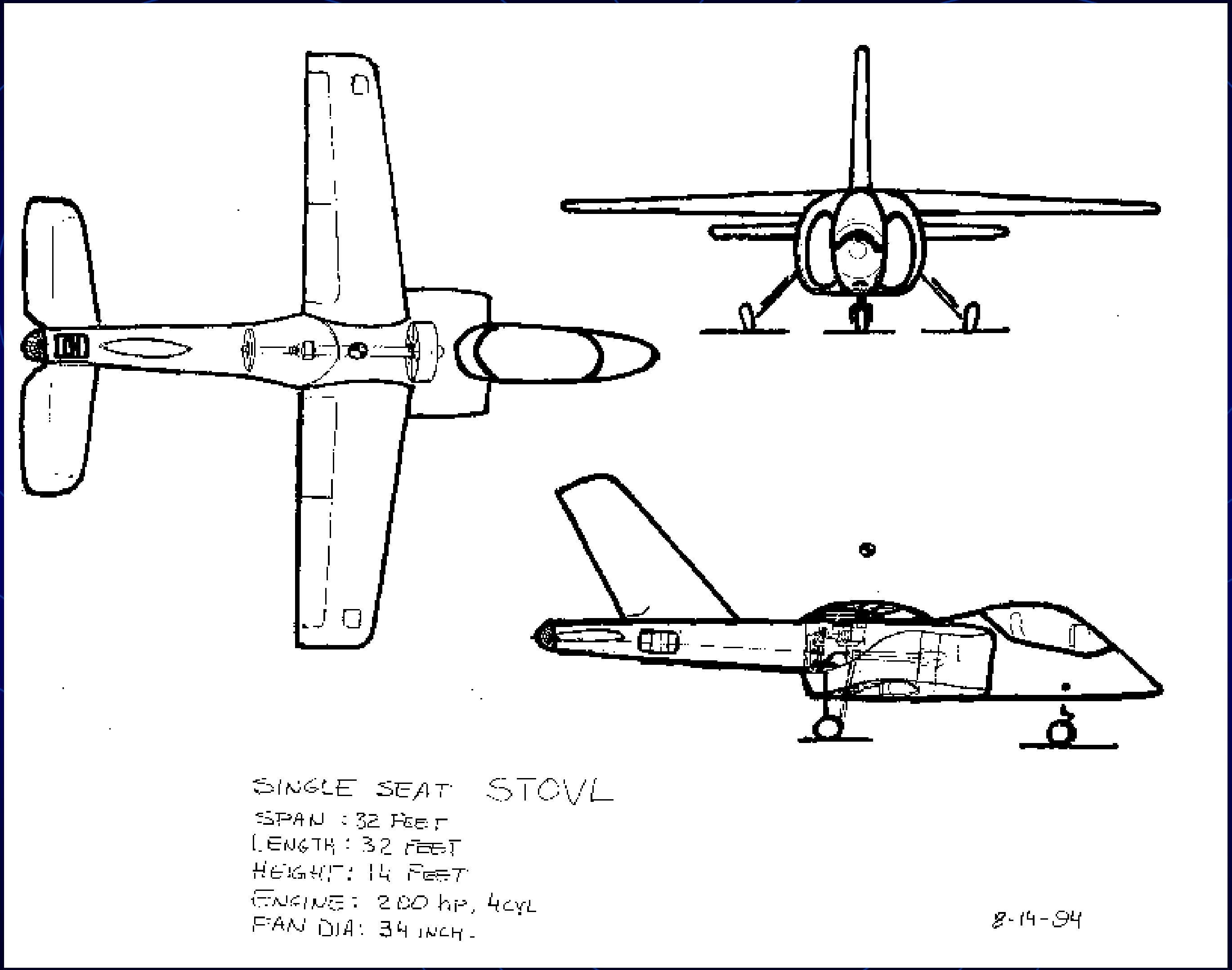
Something besides the Harrier



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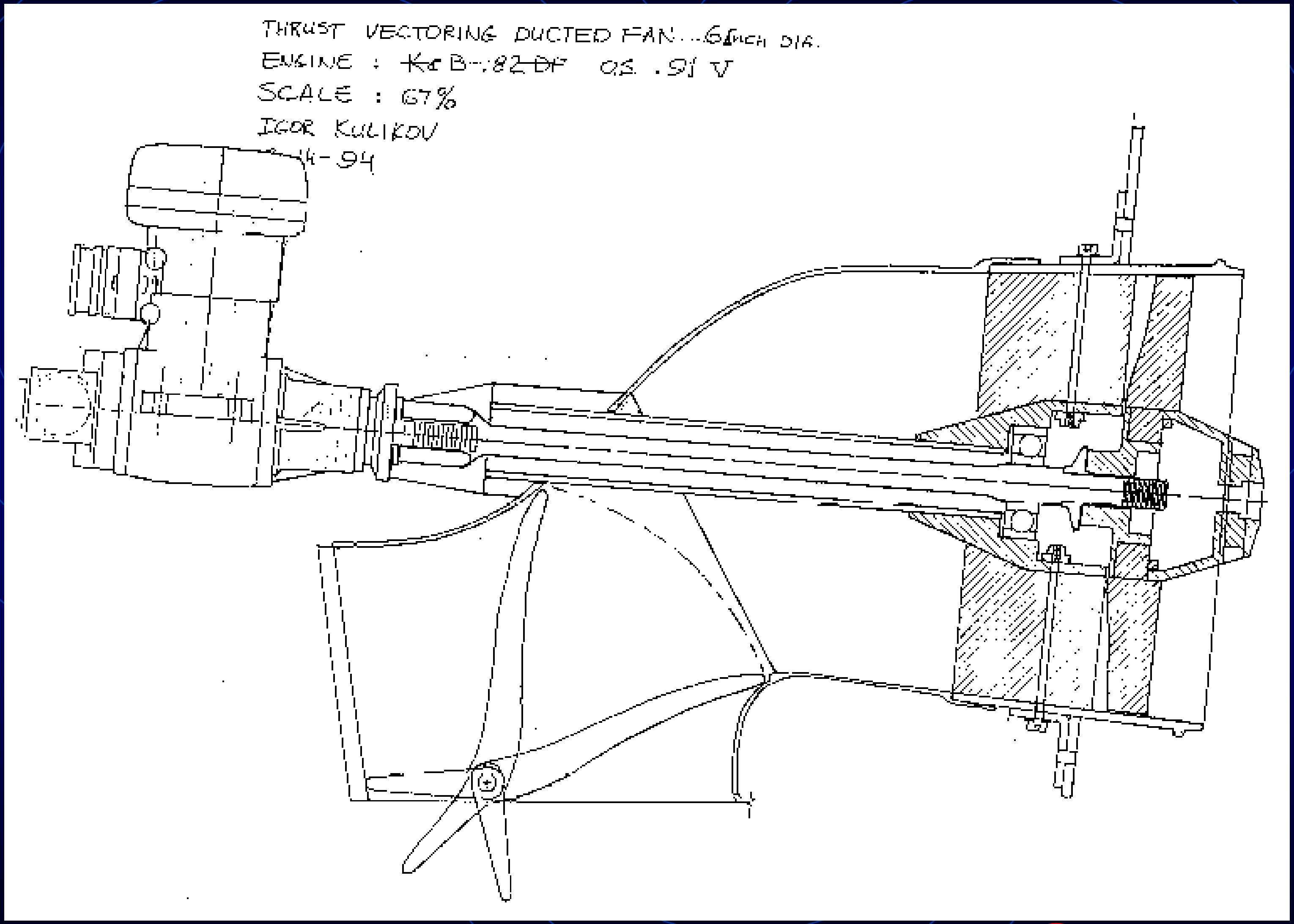
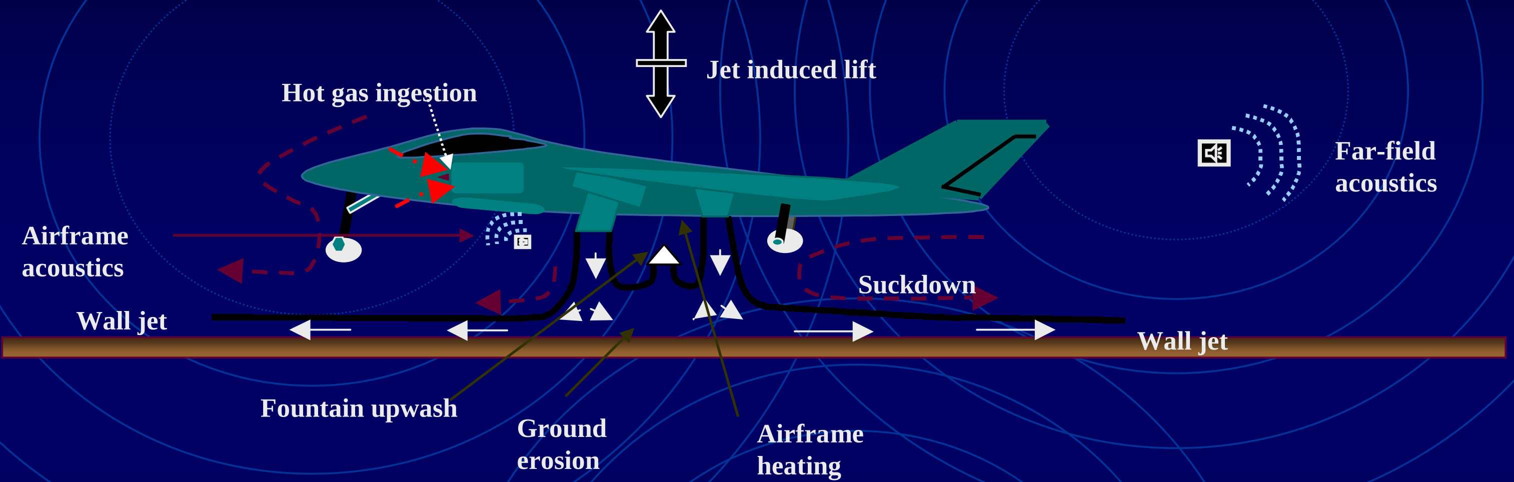
Something besides the Harrier



Problems with STOVL

- STOVL Aircraft experiences problems in the hover mode
  - *Lift Loss* – Suck-down force on the aircraft
  - *Sonic Fatigue* – Acoustic loading due to the interaction of the noise components and the structural elements
  - *Engine Failure* – Fountain Flow leading to Hot Gas Ingestion
  - *Ground Erosion* – High velocity Wall Jet causes excessive friction

STOVL Aircraft in Ground Effect



Flowfield created by the propulsion system around a STOVL aircraft.

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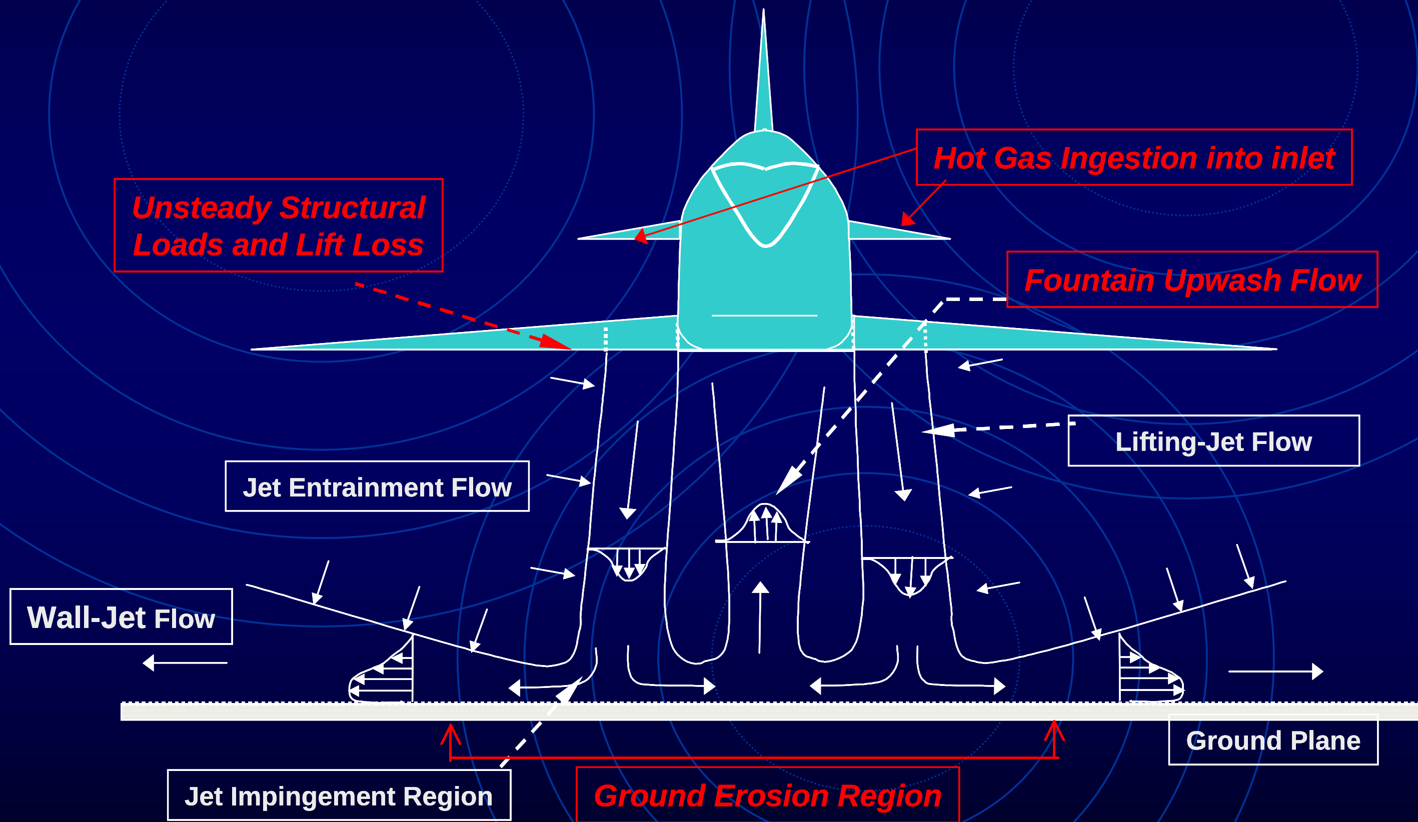
STOVL Aircraft in Ground Effect



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Lift Loss

- Entrainment caused by wall jet creates a lower area of pressure below the aircraft
- This creates a downward force which negates a portion of the generated lift

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Lift Loss

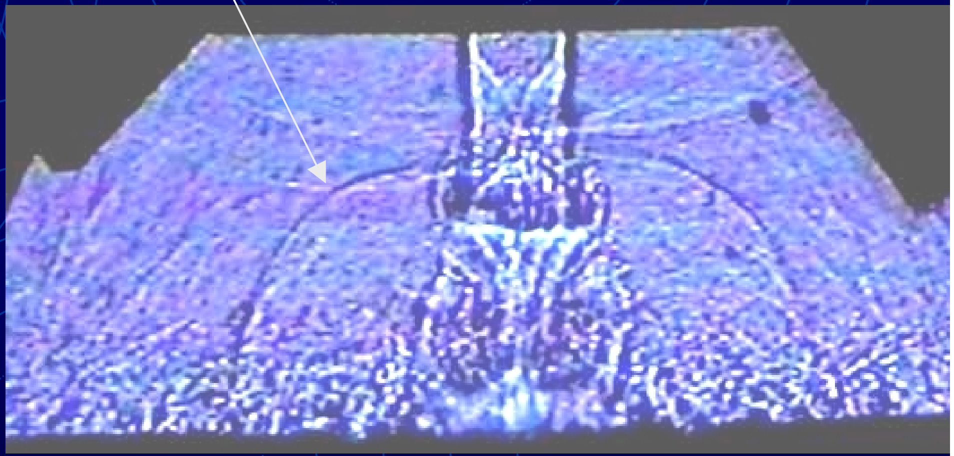
- Lift comes from two possible places
  - Conventional wing lift
  - STOVL jet generated lift
- Conventional wing lift values are found experimentally
- Jet generated lift is much simpler
- Conservation of Momentum

$$F_{lift\,x} = \dot{m}_{out} \cdot V_{x_{out}} - \dot{m}_{in} \cdot V_{x_{in}} = (\rho \cdot A \cdot V_{total}) \cdot (V_{x_{out}} - V_{x_{in}})$$
$$F_{lift\,y} = \dot{m}_{out} \cdot V_{y_{out}} - \dot{m}_{in} \cdot V_{y_{in}} = (\rho \cdot A \cdot V_{total}) \cdot (V_{y_{out}} - V_{y_{in}})$$

Sonic Fatigue

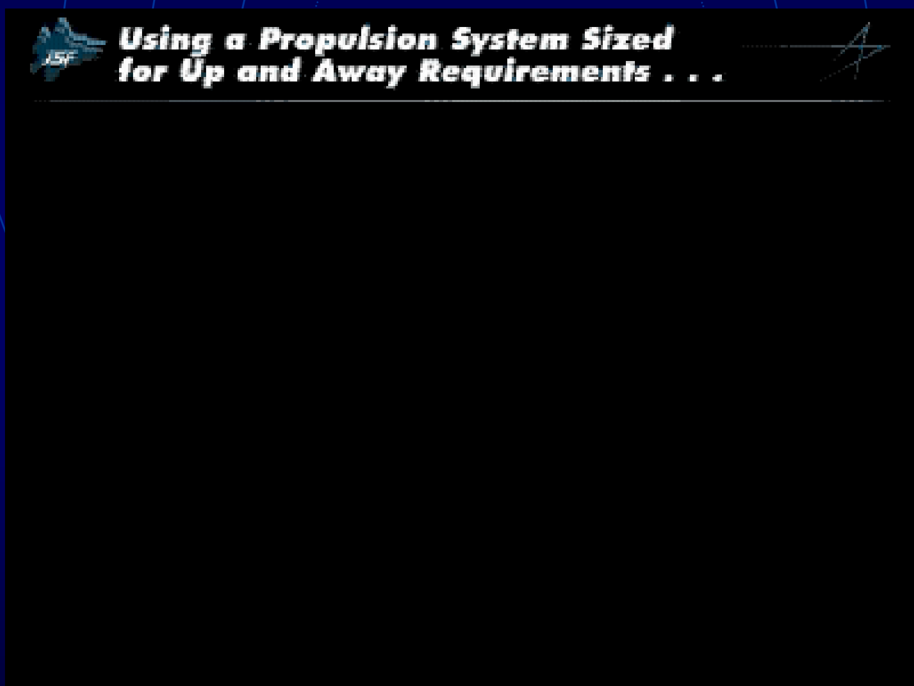
- Loud noise issuing from nozzles and turbulent flow causes large amounts of loading on jet airframe
- Noise has characteristic frequencies
- Concern is with this frequency matching the airframes resonant frequency

Acoustic wave



Shadowgraph image from STOVL lab of an ideally expanded jet

Hot Gas Ingestion

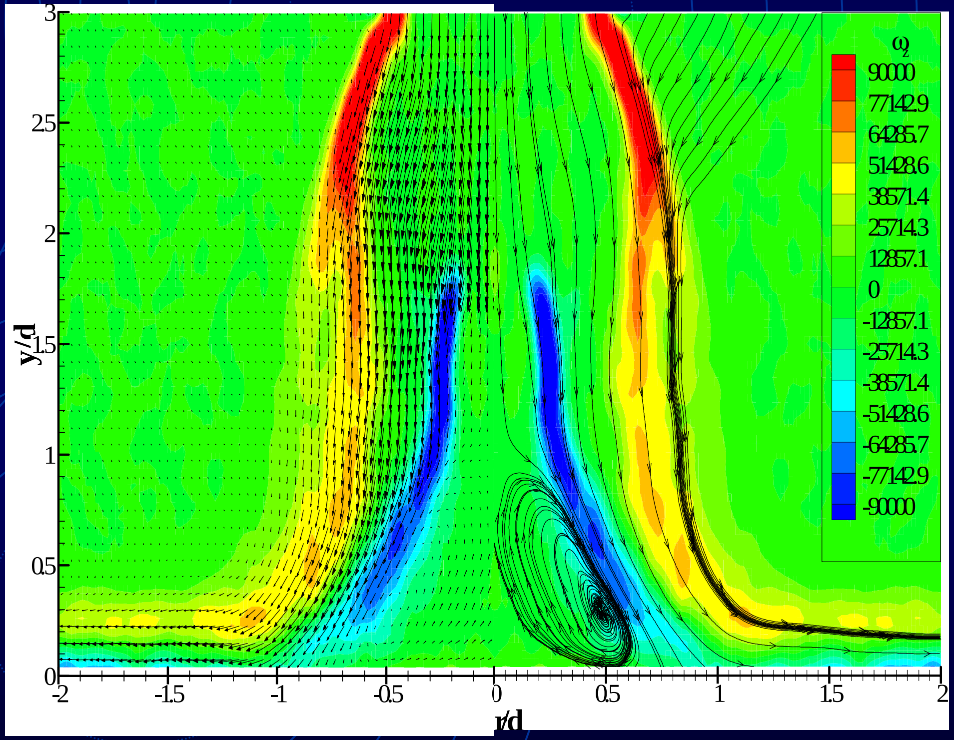


Lockheed JSF solution to Hot Gas Ingestion

- Hot exhaust gases reflect back up toward the jet and gets recirculated through the engine
- This causes an even higher temperature of exhausting gas till the point of turbine failure
- Harrier uses water to cool the turbine blades
- The tank has a size of 60 US gallons which corresponds to about 90 seconds of sustained hover

Ground Erosion

- The high velocity downward lift jets impinge on the ground when in proximity to the ground
- The friction resulting from this impingement causes extreme erosion



Velocity Field Test Field

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Ground Erosion

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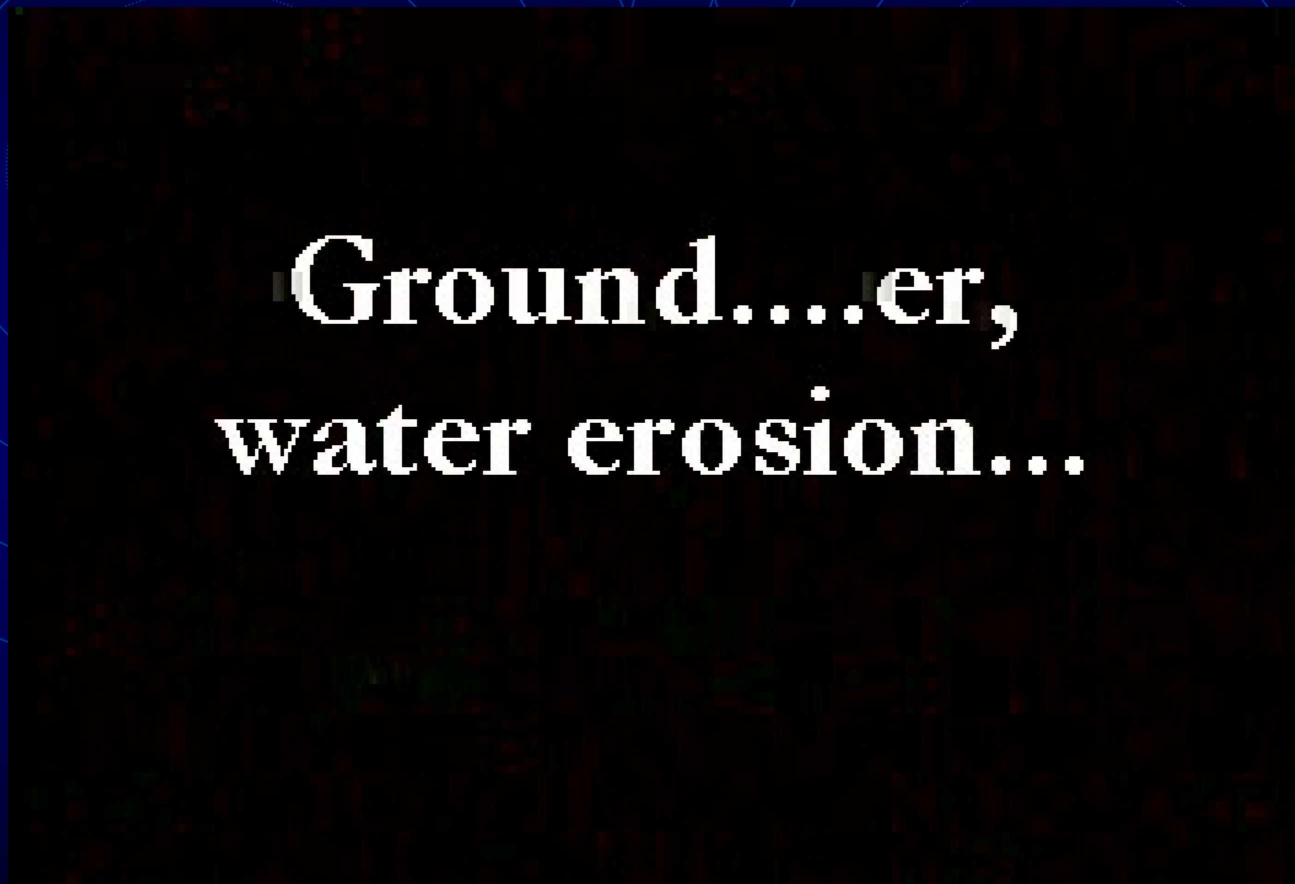
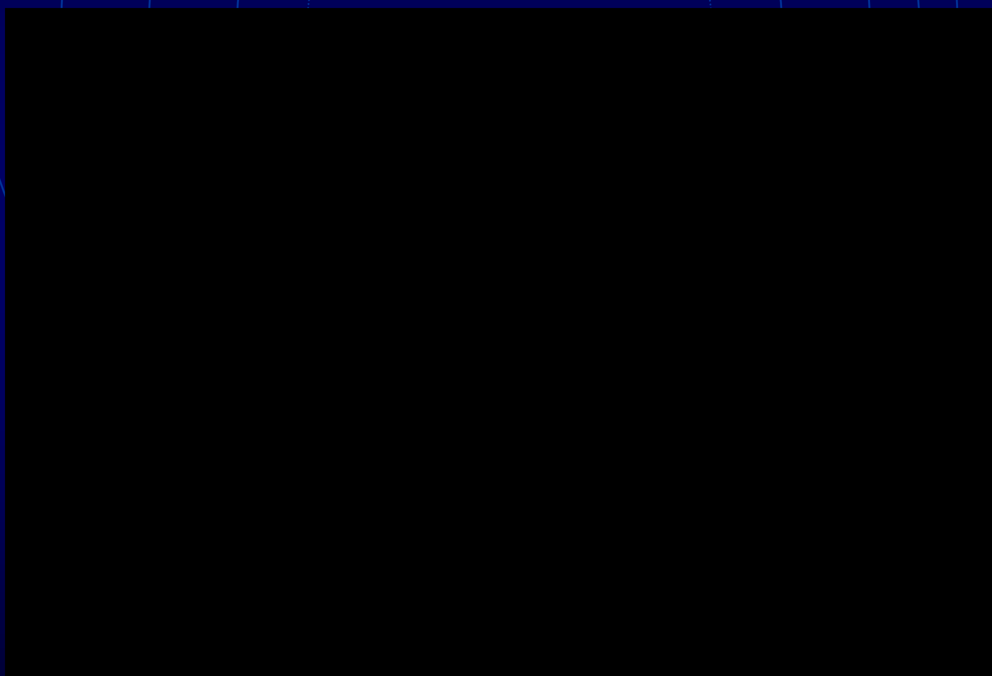
Ground Erosion



Future of STOVL



courtesy of Lockheed Martin

Lockheed-Martin Link

- The Marine Corps. version of the future Joint Strike Fight (JSF) is to utilize STOVL
- New obstacles
  - keep nozzles stealthy
    - Accomplished by placing the nozzles behind bay doors
  - Impinging Jet is supersonic

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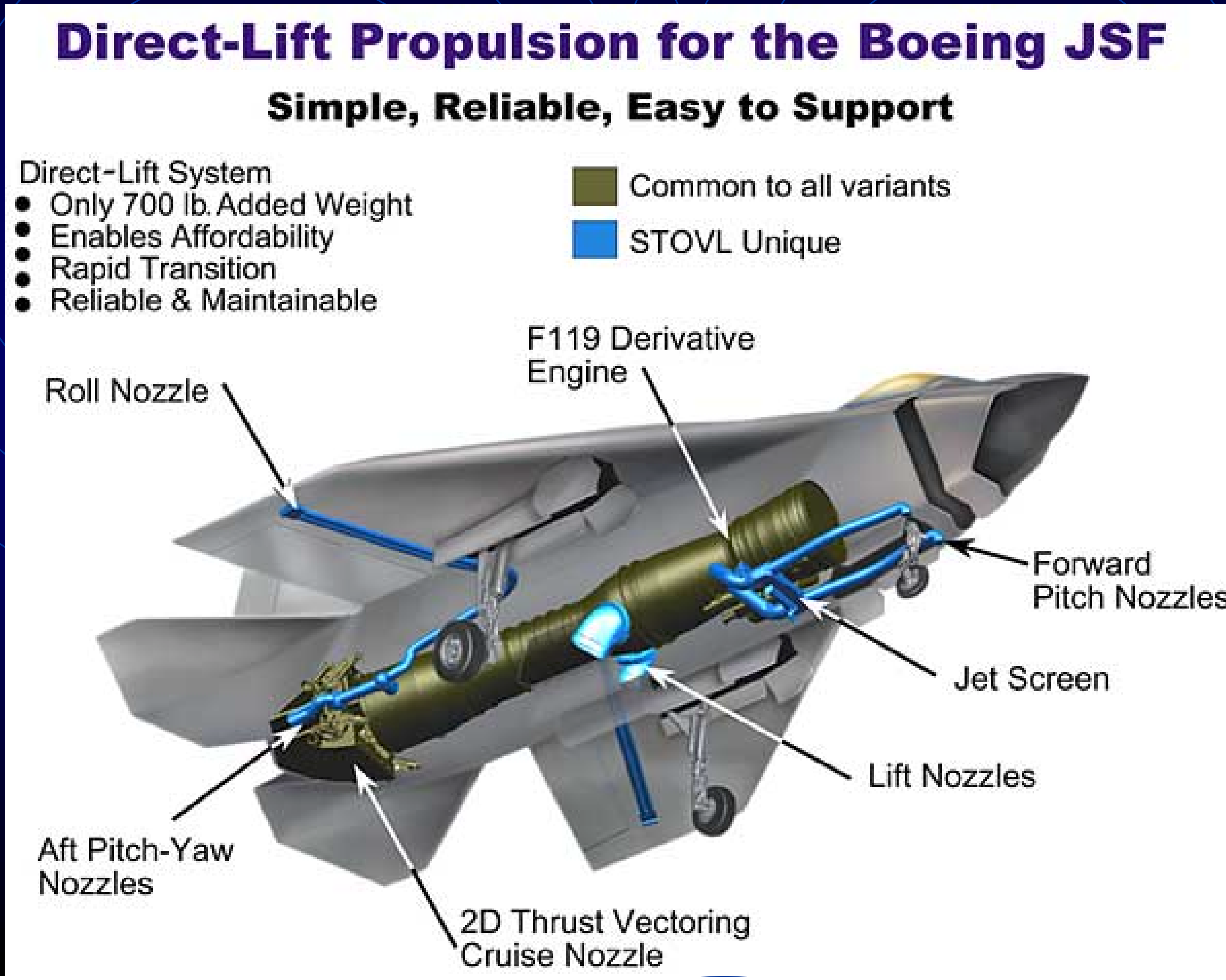
Future of STOVL



Research Aspect

Experimental Facility

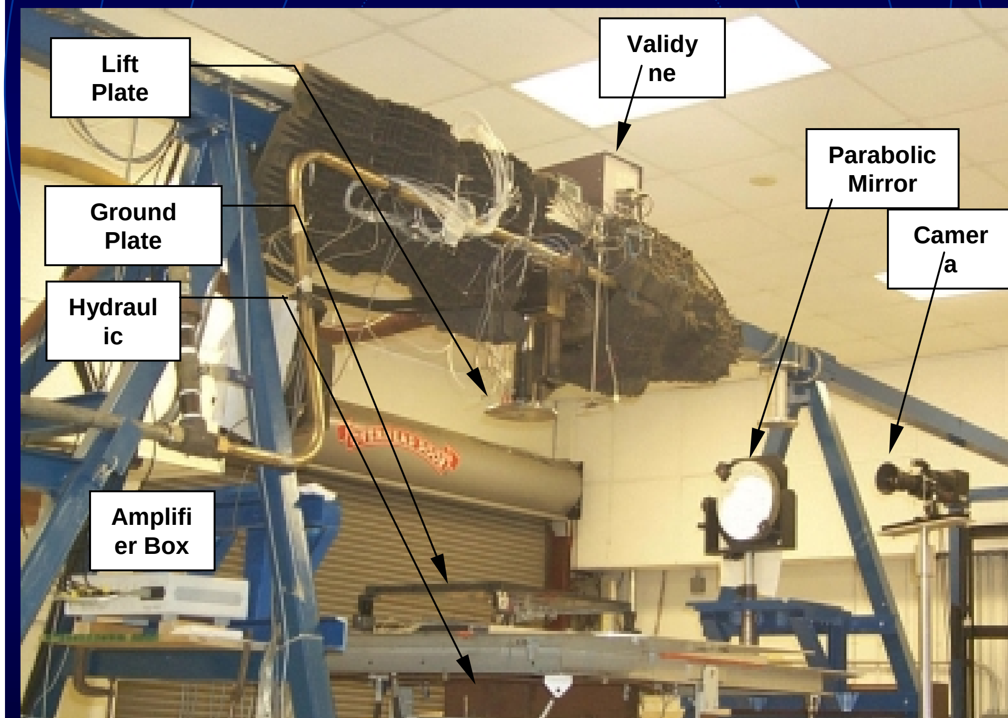


Figure 2.1 - STOVL facility

- STOVL Lab at the Fluid Mechanics Research Laboratory (FMRL) on FSU Campus
- Research done by/under: Dr. Krothapalli, Dr. Shih, and Dr. Alvi (among others)

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Experimental Facility

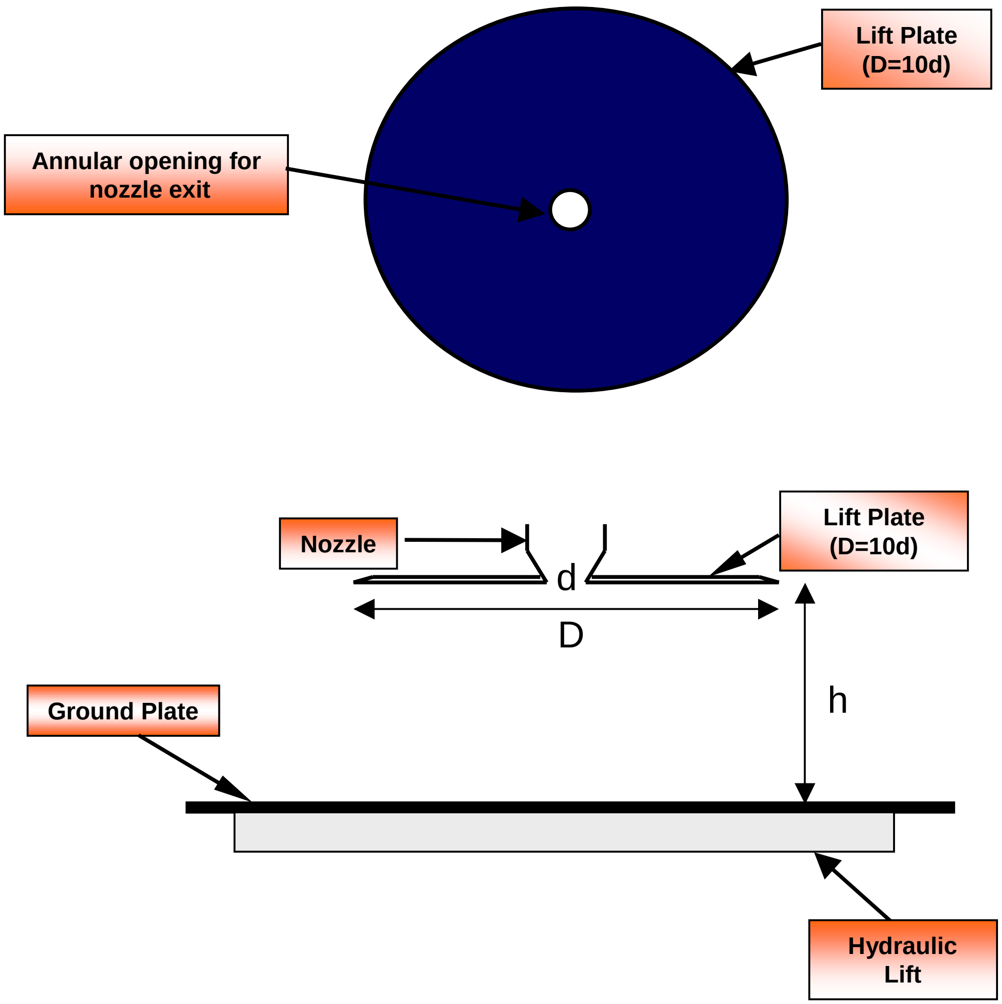
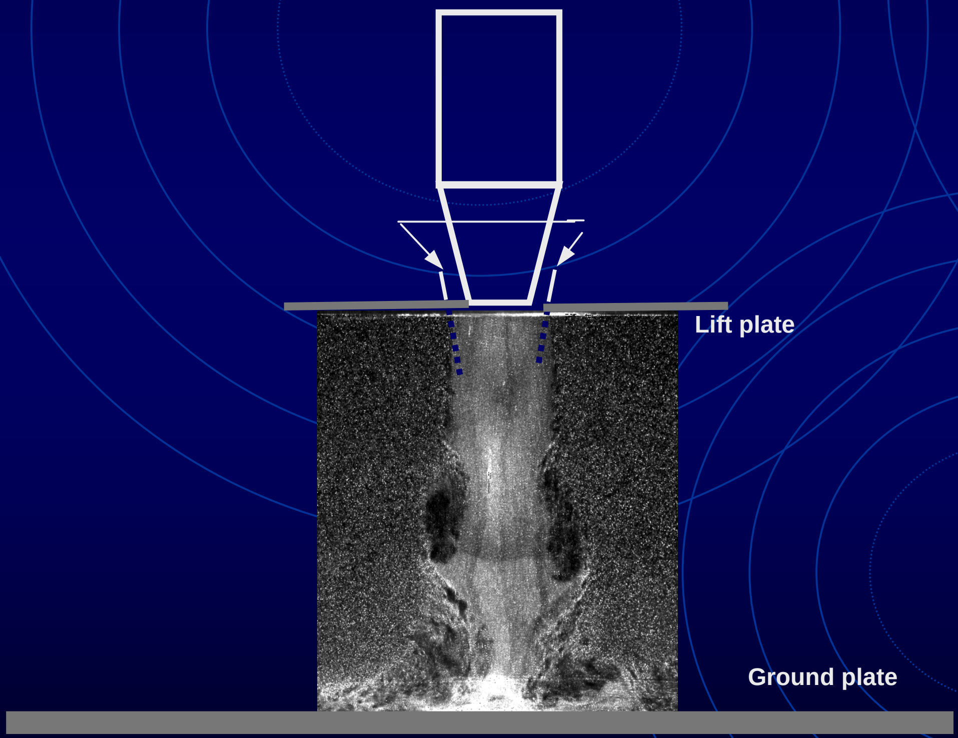


Figure 2.4 - Test geometry and configuration

Experimental Facility



- Variables:
  - Ground Plane height
  - Jet plenum pressure
    - Under-expanded jet
    - Ideally-expanded jet
    - Over-expanded jet
  - Jet geometry
    - Nozzles
      - Mach 1.0 C nozzle
      - Mach 1.5 C-D nozzle
    - # of nozzles
    - Shape of nozzles

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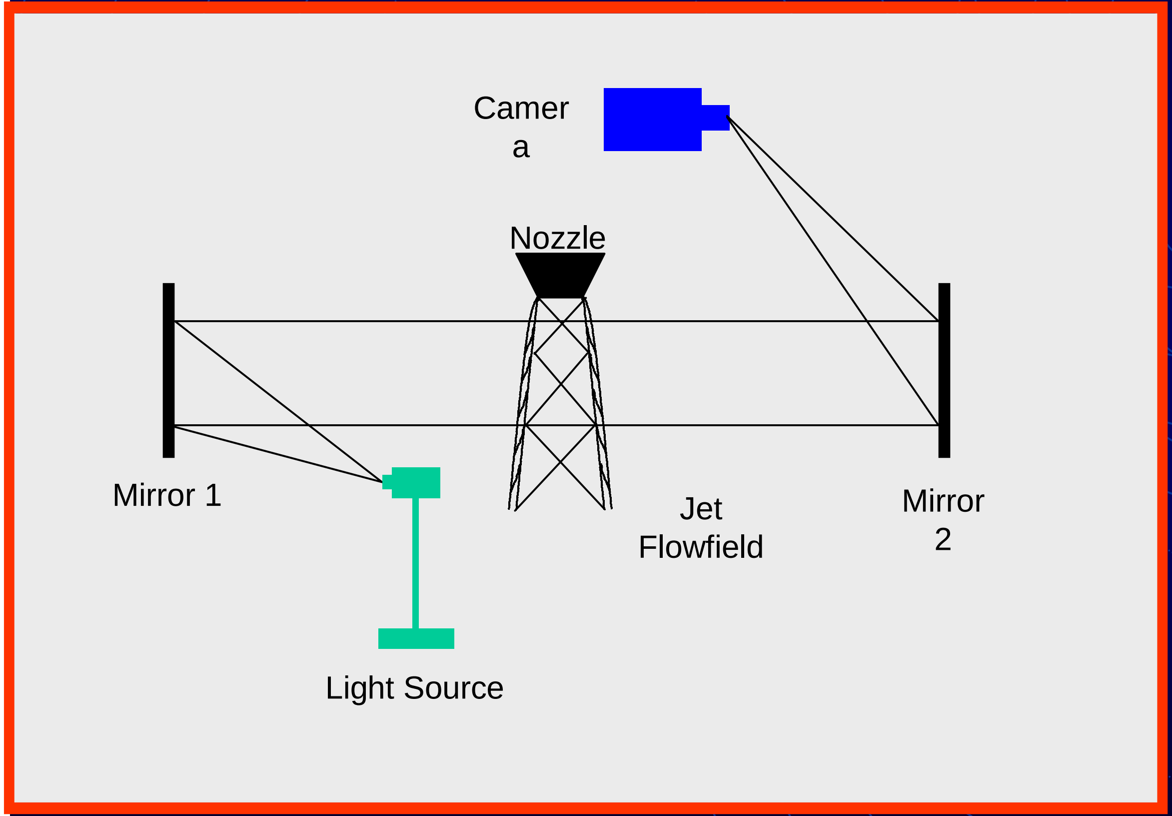
Experimental Facility



A note on photography

- Schlieren optical system used for photo and video capture
- Schlieren makes changes in density evident, the same as a mirage

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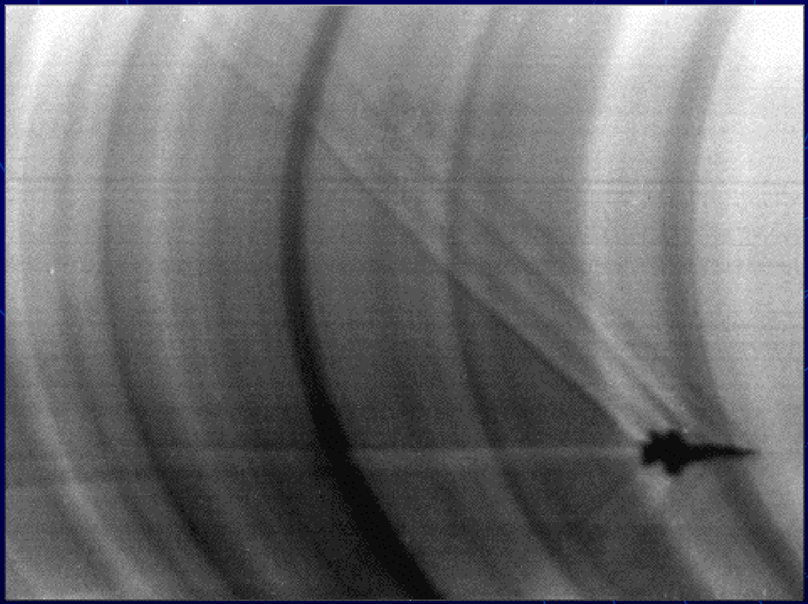
Experimental Facility



F-18 @ Mach 1.4 and 35,000 feet

- Schlieren images aren’t uncommon, you’ve most likely seen it, just didn’t know its name

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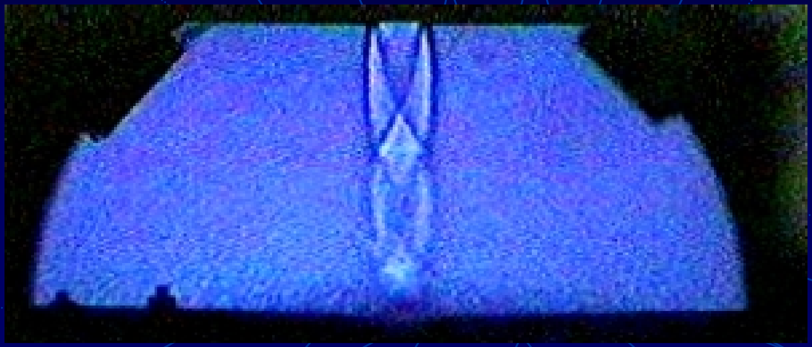
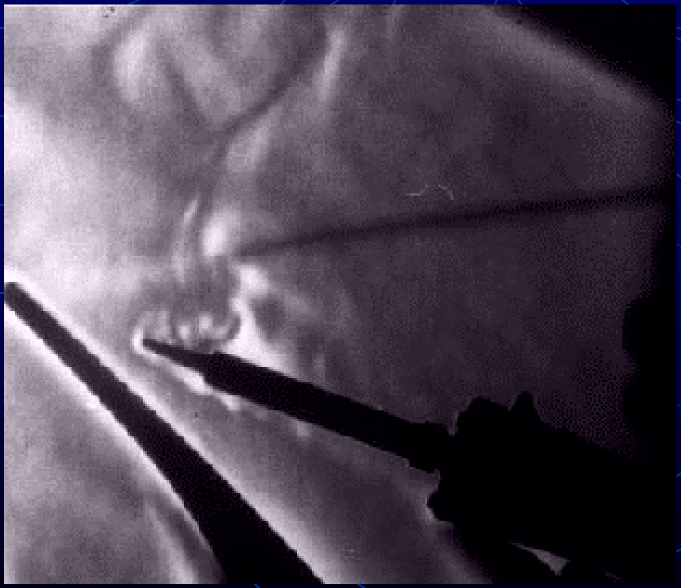
Experimental Facility

Schlieren & Shadowgraphs are Good for such things as:



A clear jet



Heat convections

Web link

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Experimental Facility

Supersonic Particles & Shock waves

Bullet piercing aluminum foil

Web link

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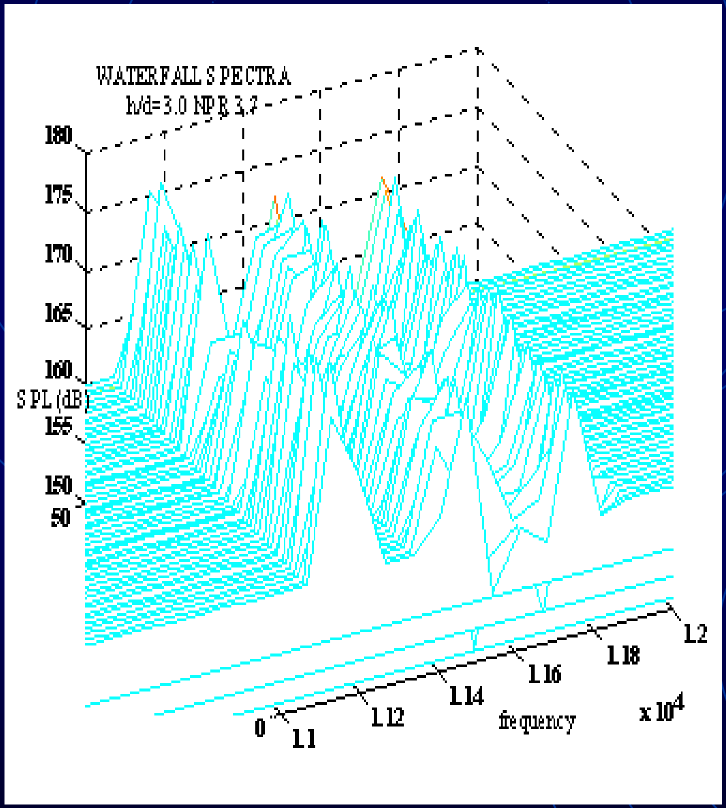
Recent Experiments



- Kartik Iyer
  - “Mean and Unsteady Flowfield properties…”
- Guarav Garg
  - “Flowfield characteristics of a Supersonic…”
- Current research
  - Huadong Lou
    - Active control of a Supersonic STOVL jet

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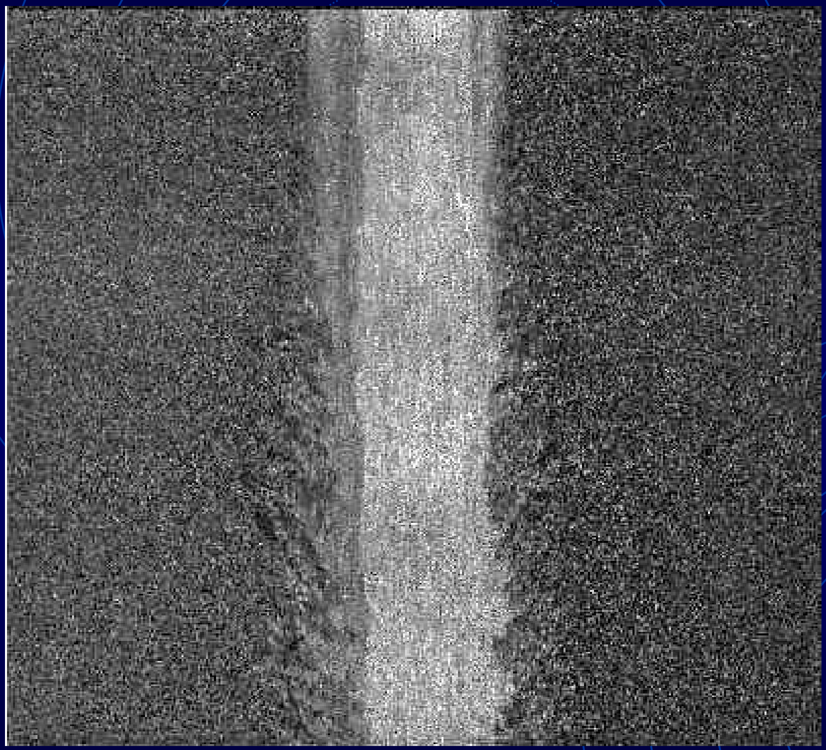
Flow Visualization of a M = 1.5 Supersonic jet



Free Jet

Impinging Jet

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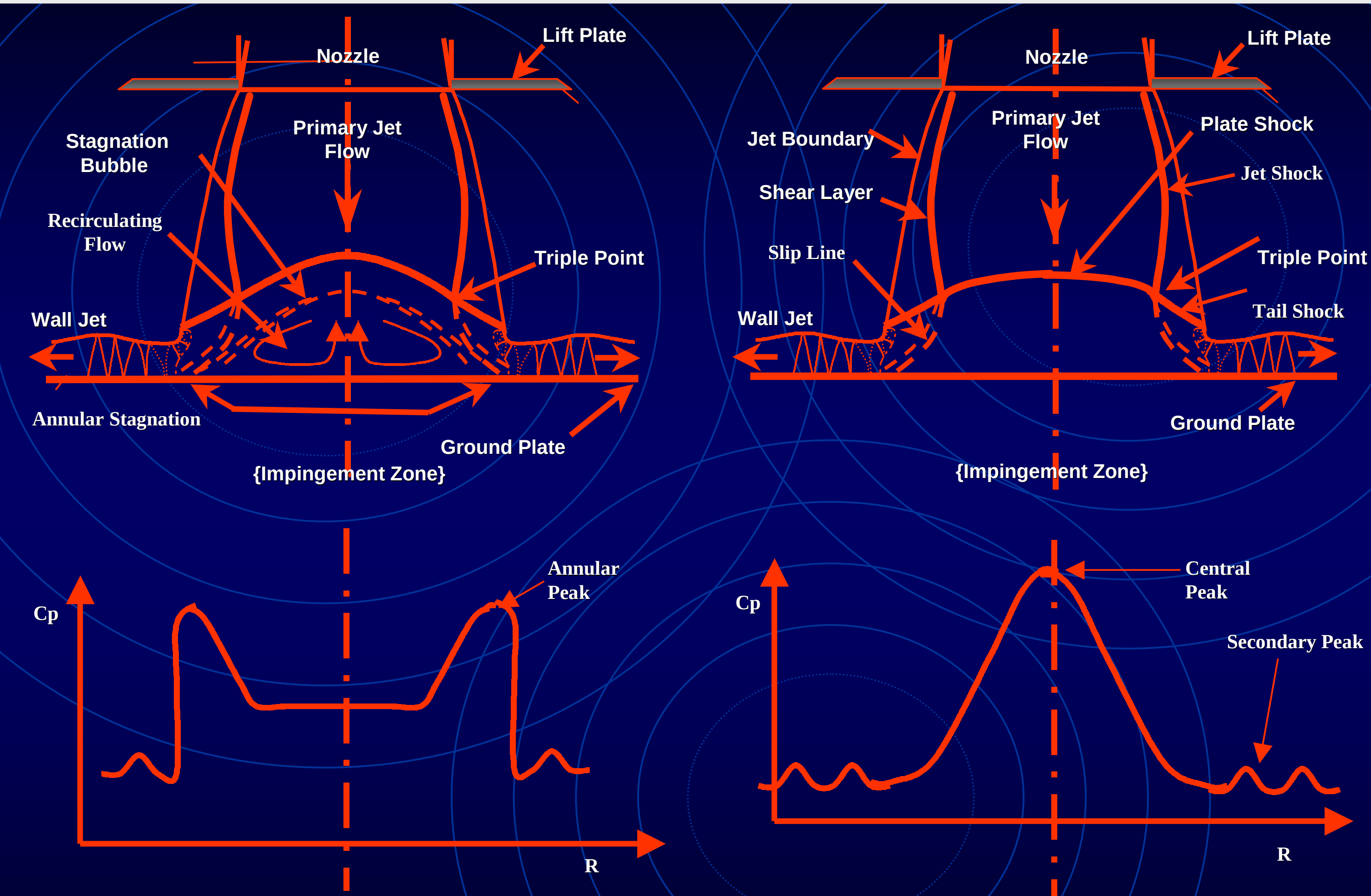
Flowfield Schematic



Stagnation Bubble Flowfield

‘Normal’ Flowfield

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Acknowledgements

- A. Krothapalli, E. Rajkuperan, F. Alvi, L. Lourenco: "*Flow field and noise characteristics of a supersonic impinging jet*"; J. Fluid Mech. (1999), vol. 392, pp. 155-181; 1999 Cambridge University Press
- F.S. Alvi and K. G. Iyer: "*Mean and Unsteady Flowfield properties of supersonic impinging jets with Lift Plates*"; AIAA 99-1829, 1999.
- R. Elevarasan, L. Lourenco, L. Venkatakrishnan, A. Krothapalli: "*Application of PIV to Large Scale STOVL Supersonic Jet Facility*"; AIAA 99-0271, 1999.

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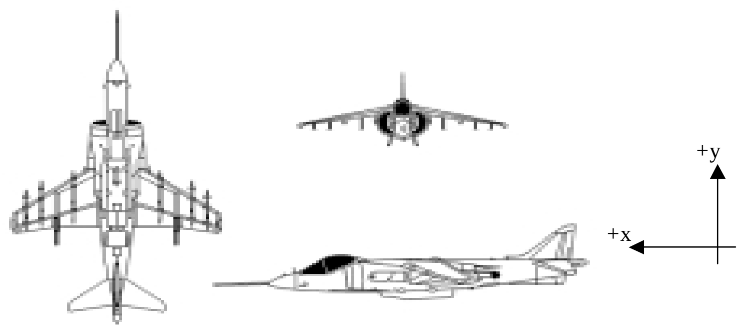
Questions? Comments?

no time like the present

Homework

STOVL Presentation Homework **Due Oct. 29, 2001**

First derive…. Just kidding! Given the specifications below, calculate first the percentage of engine thrust (not vertical thrust) required to make the Harrier "hover" a fair distance from the ground (no lift loss). Assume that only 70% of the engine thrust can be redirected through the nozzles to give vertical thrust. Next calculate the velocity, in Mach number, of the air exiting each vertical nozzle at full thrust when the nozzles are at 90 degrees (vertical). Lastly, find the angle at which the vertical nozzles must be positioned to make the plane "hover" in a stationary position. Assume that this particular Harrier has the Rolls Royce F402-RR408 turbofan engine. Exiting gas properties: γ=1.33, R=0.287kJ/kg·K, T=1750K.



Primary Function : Attack and destroy surface targets under day and night visual conditions

Contractor : McDonnell Douglas

Power Plant : One Rolls Royce F402-RR-406 or F402-RR-408 turbofan engine

Thrust : F402-RR-406: 21,500 pounds ; F402-RR-408: 23,400 pounds

Length : 46.3 feet (14.11 meters)

Wingspan : 30.3 feet (9.24 meters)

Speed : Subsonic to transonic, 585 kts (1.0 Mach)

Weight : 14,867 lb

Nozzle Outlet Area: # ft^3

Intake area: # ft^3

Engine's mass flow rate at full thrust: # lb_m/s

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