UCAV Aerodynamics and Vehicle Control in the Naval Environment

Terence A. Ghee

Presented to the Aerodynamic Issues of Unmanned Air Vehicles Workshop, 5 November 2002, Bath University, Bath, UK

NAVAIR 4321 Advanced Aerodynamics Branch,
Bldg. 2187, Ste. 1320B, Patuxent River, MD 20670-1906 USA
301-342-8536, gheeta@navair.navy.mil

NAVAL AVIATION TECHNOLOGIES

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **26 JUL 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **UCAV Aerodynamics and Vehicle Control in the Naval Environment**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NAVAIR 4321 Advanced Aerodynamics PatuxentRiver, MD 20670-1906 USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001685, CSP 02-5078, Proceedings for Aerodynamic Issues of Unmanned Air Vehicles (UAV)., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**30**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

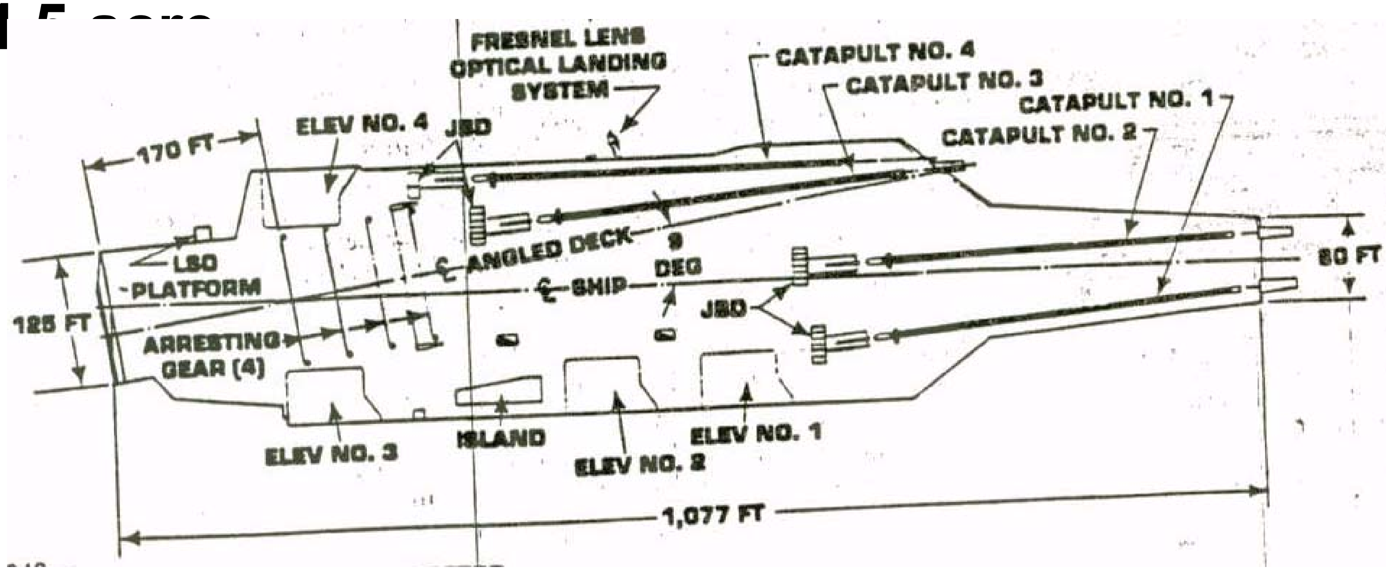
Outline

- **Introduction**
- **Naval Aviation Characteristics**
  - Naval Environment
  - Day/Night Operations
  - Aircraft Structure
  - Catapult Launch
  - Recovery
- **Specific UCAV Concerns**
- **Current NAVAIR 4321 Research**
- **Summary**

Introduction

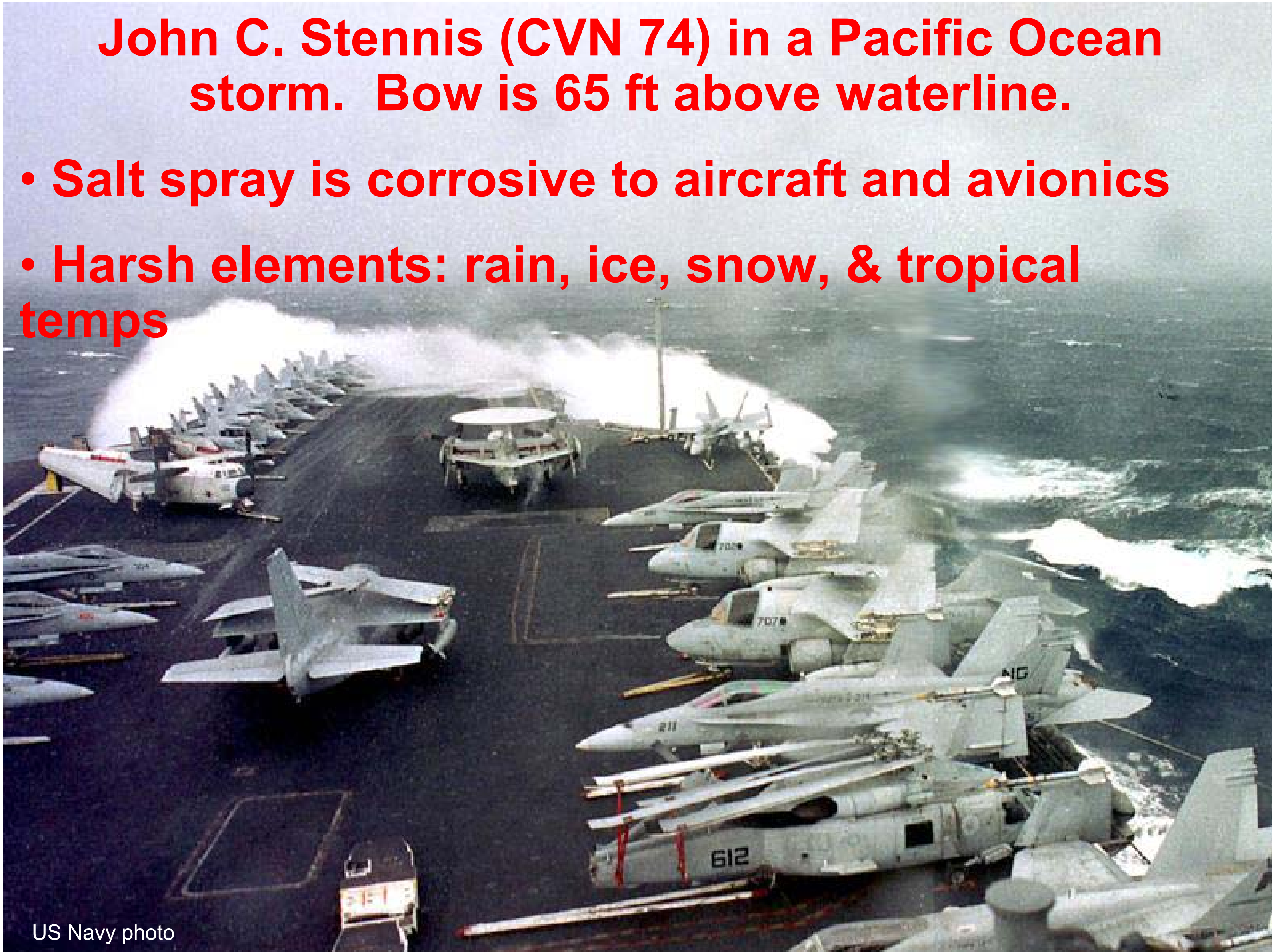
Nimitz class (CVN)

- Length: nearly 1100 ft
- Speed: 30+ kts. More speed = more WOD = lower approach speed
- Four catapults: 0 to 152 kts in 2.5 s (F/A-18)
- Flight deck: 4
- Crew: 5680
- Aircraft: 85



NAVAIR

The Naval Environment



John C. Stennis (CVN 74) in a Pacific Ocean storm. Bow is 65 ft above waterline.

- **Salt spray is corrosive to aircraft and avionics**
- **Harsh elements: rain, ice, snow, & tropical temps**

US Navy photo

NAVAL AVIATION TECHNOLOGIES

Day and Night

- **Ability to launch every 37 seconds in daytime, 1 minute at night**
- **Recovery every 30 to 45 seconds (longer interval at nigh**

US Navy photos

Aircraft Structure

- **Landing gear (LG) must be designed for large catapult and recovery loads**
- **Landing gear withstands approximately 3X CTOL landing loads**
- **Arrestment requires "beefing" tail structure. 2.5X CTOL arrestment loads**
- **Catapult loads of nearly 5X gross weight, Drag brace on nose gear (NG) can have nearly 6X gross weight**

US Navy photos

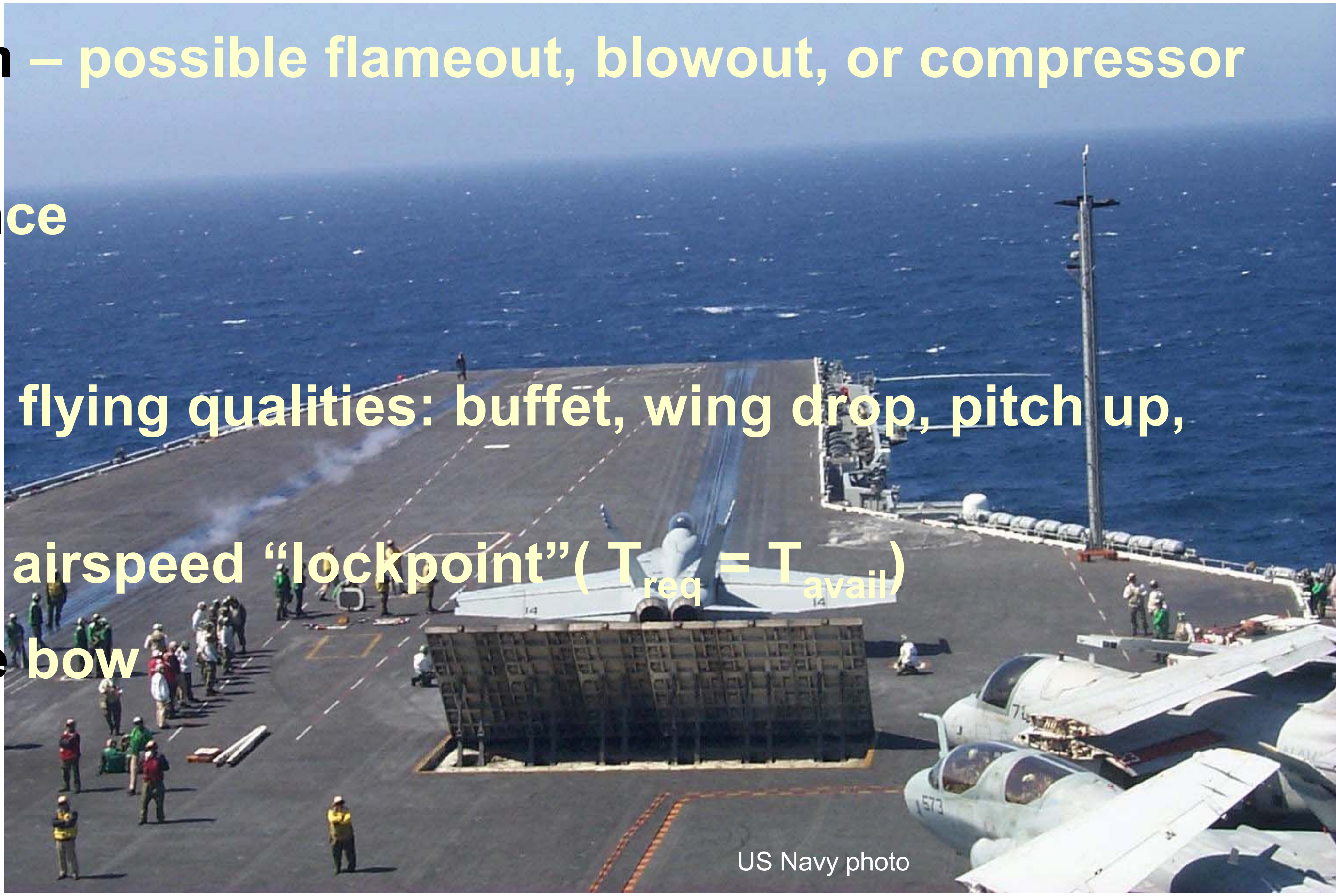
Aircraft Structure

- Wing fold mechanism required for aircraft stowage
- Larger wing/high lift system for lower approach speeds can lead to need for large horizontal tail (HT)
- Achieve balance between high C_L while maintaining acceptable C_m
- Aerial re-fueling capability
- Weight penalties of stronger landing gear & high lift systems must not unduly impact performance

US Navy photos

Catapult Launch

- Launch a 50,000 lb vehicle 0 to 150 kts (300 ft) in 2.5 seconds
- Re-ingestion of hot exhaust gas can occur when an air vehicle is operating in front of the Jet Blast Deflector (due to WOD, rare)
- Steam ingestion – possible flameout, blowout, or compressor stall of engine
- Gust & turbulence
- $V_{min.\ end\ speed}$:
    - Acceptable flying qualities: buffet, wing drop, pitch up, etc.
    - Proximity to airspeed "lockpoint"($T_{req} = T_{avail}$)
    - Sink off the bow
    - Stall speed



US Navy photo

Recovery

- Ramp to end of angled deck: 780 ft, #4 wire less than 300 ft from ramp
- Lateral deviation from centerline: +/- 20 ft
- Constant γ, constant α, no flared landing!
- Ship "burble"/ship motion can cause high touchdown speed or rolled/yawed attitude
- Adequate thrust, attitude control, stall margin needed

US Navy photos

- Bolter/wave-off characteristics – very dynamic, LG and propulsion characteristics, HT size, C_D. Criteria either NG lift off before end of deck or pilot's eye must stay level

Advantages for UCAV-N

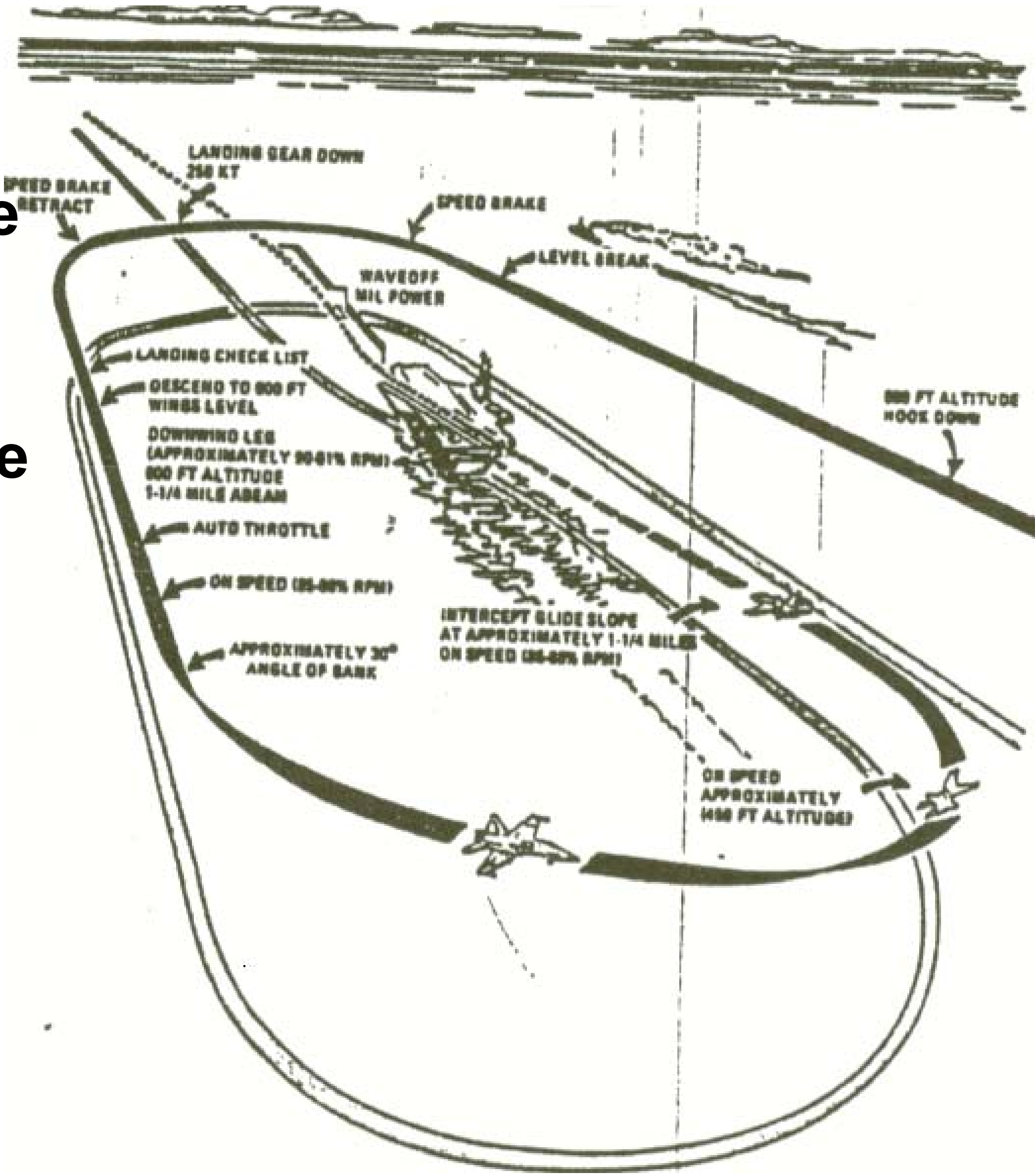
- **Flying qualities: avoids PIO (No problem with pilot discomfiture of rates)**
- **Not G limited (pilot)**
- **Elimination of pilot and crew systems can add to range, endurance, or payload increases**
- **No powered approach (PA) angle-of-attack visual constraints**
- **Reduction in manpower, single personnel controls multiple UCAVs**
- **Envisioned to have less volume than comparable manned aircraft**
- **Lower O&S costs than current aircraft (50% reduction)**
- **Reduced acquisition costs**

Specific UCAV Concerns

- Aerodynamic issues not distinctly different from manned Naval aviation. However, goals of UCAV-N are challenging:
  - 12 hour endurance
  - Low signature
  - High subsonic speed
- Maneuvering on deck: how does one taxi vehicles around the flight deck, to the hangar, etc? The goal is for a single operator to control numerous UCAV.
- In-flight refueling? Need to have fine control of UCAV in close proximity of fueling aircraft for hook up and to maintain UCAV/tanker connection. Multiple UCAVs in the pattern make this more of a challenge

Specific UCAV Concerns

- Seek and avoid/situational awareness issues: on the deck and in the air.
- Interface with Air Boss, LSO, ATC. How does one communicate & control?
- Wave-off/bolter in multiple UCAV operation
- Robust vehicle health management systems needed?
- Designing for routine ops. Maintainability and reliability.



UCAV-N Status

- Naval UCAV Operational System Concept shows potential to offer tremendous multi-mission capability and affordability for carrier based operations
- Two contractor teams, Boeing and Northrop Grumman, are conducting studies, analyses, simulations, and demonstrations in a competitive environment
- Naval UCAV ATD will develop technologies to enable low risk entry to EMD for a future Naval system, should requirements dictate

Current NAVAIR 4321 Research
Deployed Serrated Flap (DSF)
Deployed Un-serrated Flap (USF)

Impetus

- LO UCAV have moderate swept wings
- Moderate swept wings can have unstable aerodynamics
- LO of air vehicles are compromised by deployed control surfaces
- Flow control devices need to be tailored to the air vehicle

Objectives of Research

- Understand flow field of moderately swept UCAV
- Use a flow control device to improve maneuver and powered approach performance
- Eliminate or reduce LO penalty associated with deployed control surface

Test Program

- **Three Phases**
  - Vortex location – completed (FY98-99)
  - Vortex quantification – completed (FY00-01)
  - Vortex control using Deployed Serrated Flaps (DSF)
    - **Initial testing of DSF/USF (FY02)**
    - **Parametric investigation (FY03)**
    - **Flow visualization of DSF/USF (FY03)**
- **Understand flow physics of UCAV with DSF**

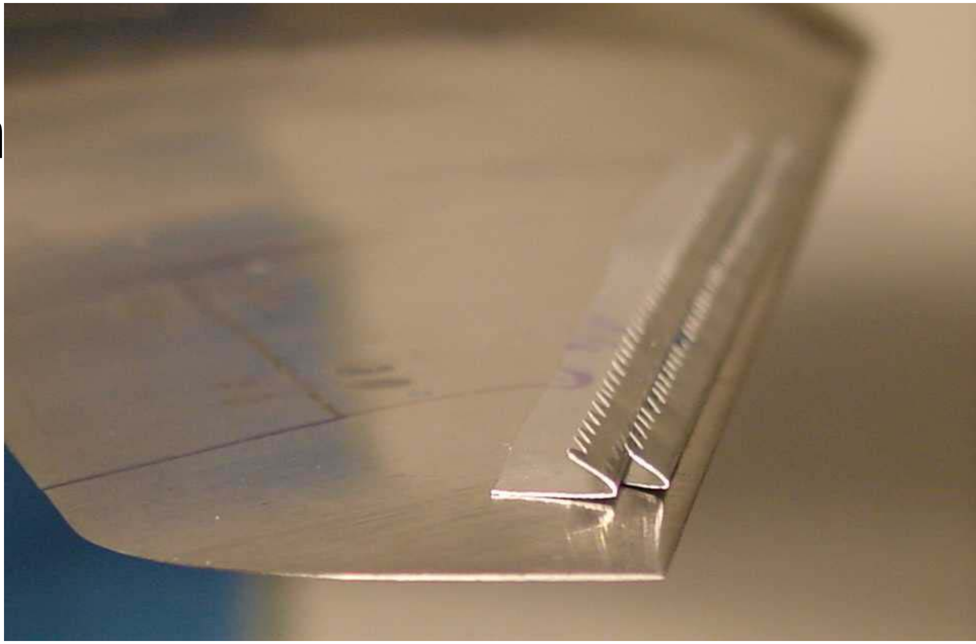
UCAV Model

- 4% scale Boeing 1303 configuration (This is <u>not</u> the UCAV-N configuration)
  - Tested previously in Boeing Polysonic WT
- Sweep = 47°
- Span = 2.160 Ft
- S = 1.210 Ft^2
- MAC = 0.765 Ft
- Inlet plugged
- Transition free

DSF

- Manufactured from 0.010” Aluminum flashing
- Serrations cut with pinking shears, bent in box brake
- Peak-to-peak amplitude of serration = 5/64” (0.85% MAC)
- Tested: Single,Tandem

&Tandem In-Opposition



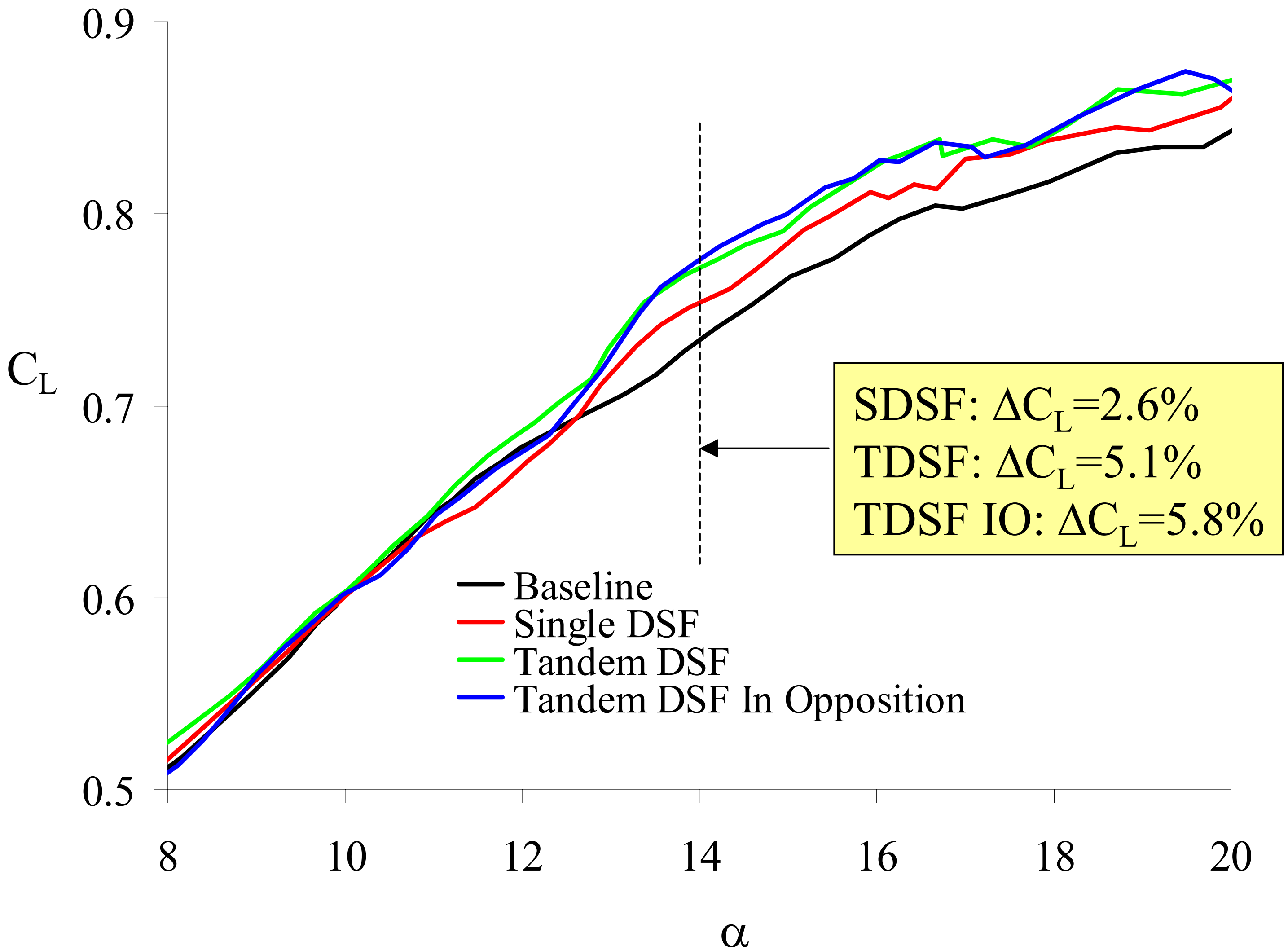
Test Conditions

- **q = 43.3 psf (V_∞ = 195), Re_{MAC} = 960,000 M_∞ = 0.17, α = -4 to 22 degrees**
- **Back-to-back repeat: all configurations $\approx$35**
- **DSF height: 0.0156 ft (3/16”) & 0.0417 ft (1/2”), 2.04% and 5.44%MAC**
- **DSF higher than BL**
- **DSF location: y/b = 0.21, 2.07% MAC from LE**

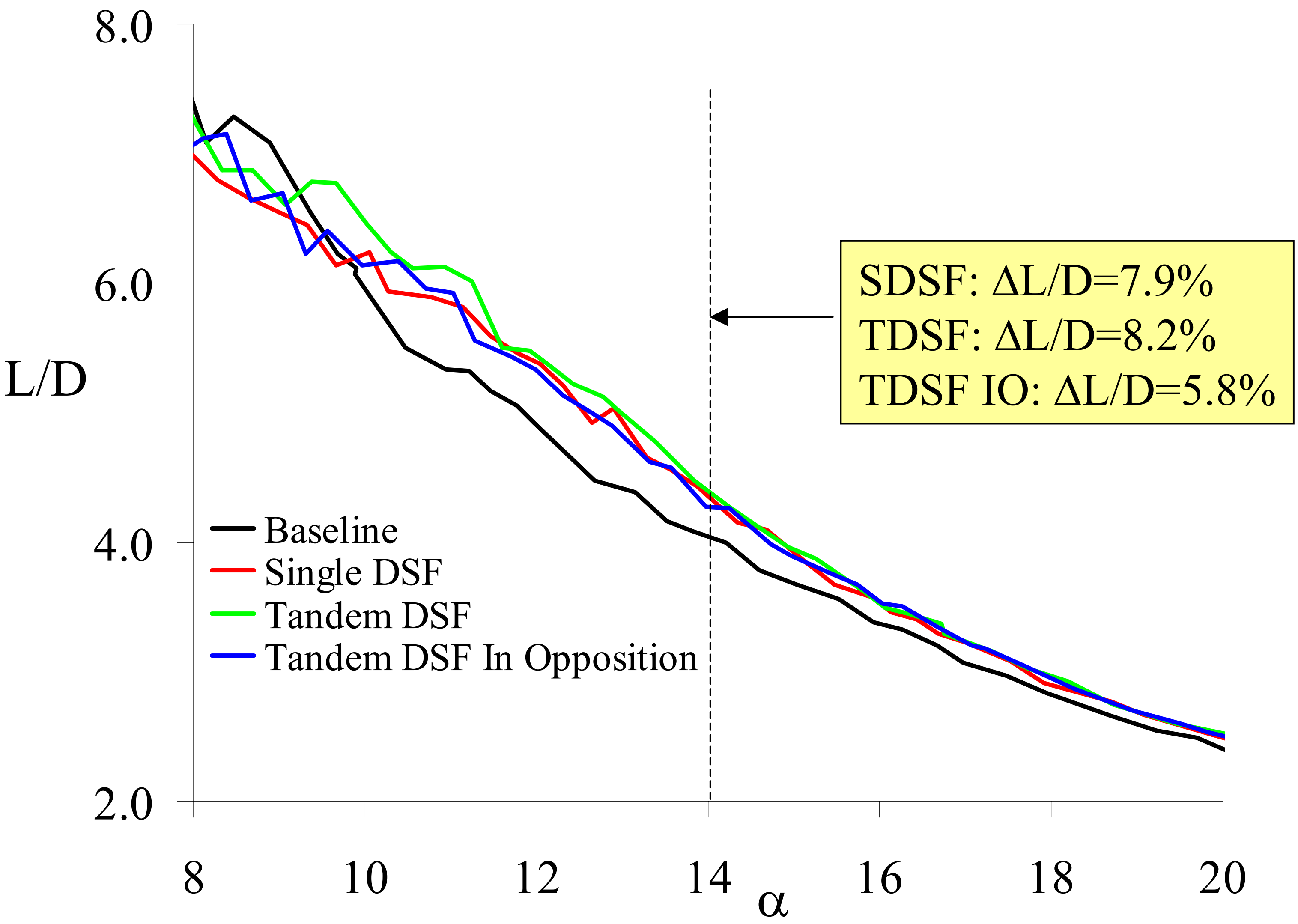
Test Conditions, cont.

- DSF length: y/b = 0.38 (each side)
- DSF deflection angle: 28 degrees
- TDSF and TDSF IO teeth aligned (chordwise)
- TDSF spacing: 1d
- TDSF IO spacing: 2d and 3d
- Flaps deployed (LEF/AIL/TEF): 0/10/10 and 0/0/20

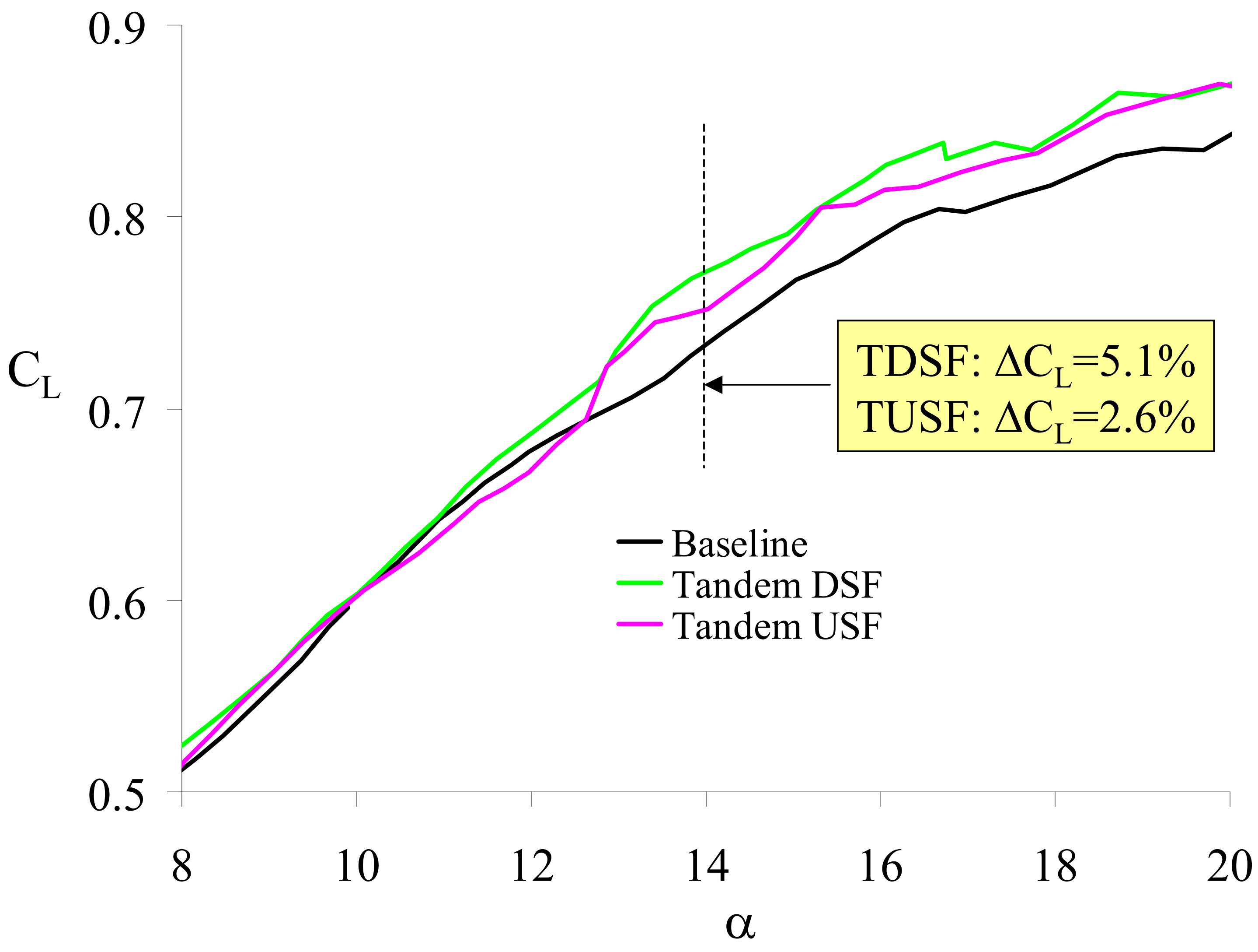
Configuration Comparison: C_L vs. α



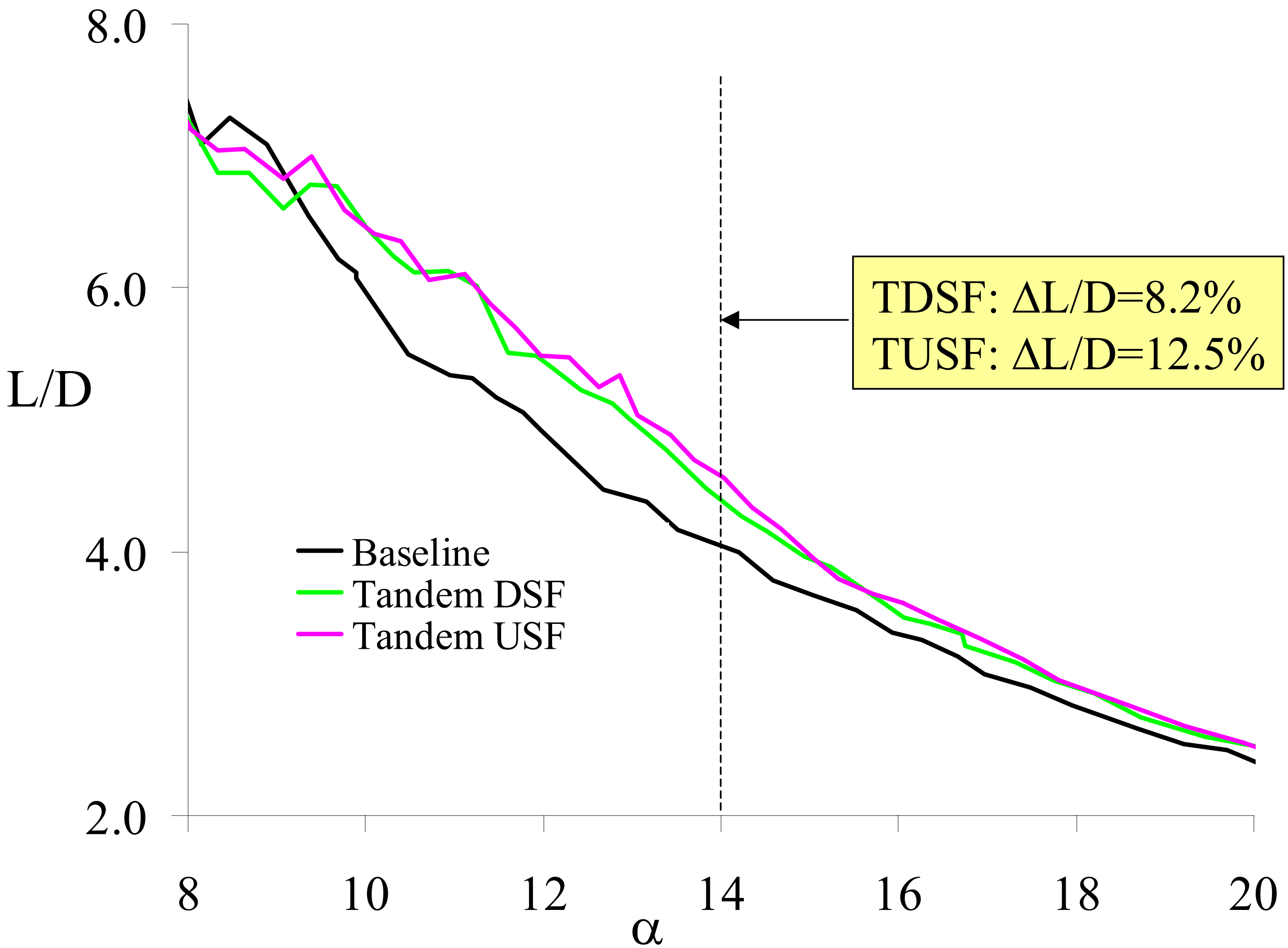
Configuration Comparison: L/D vs. α



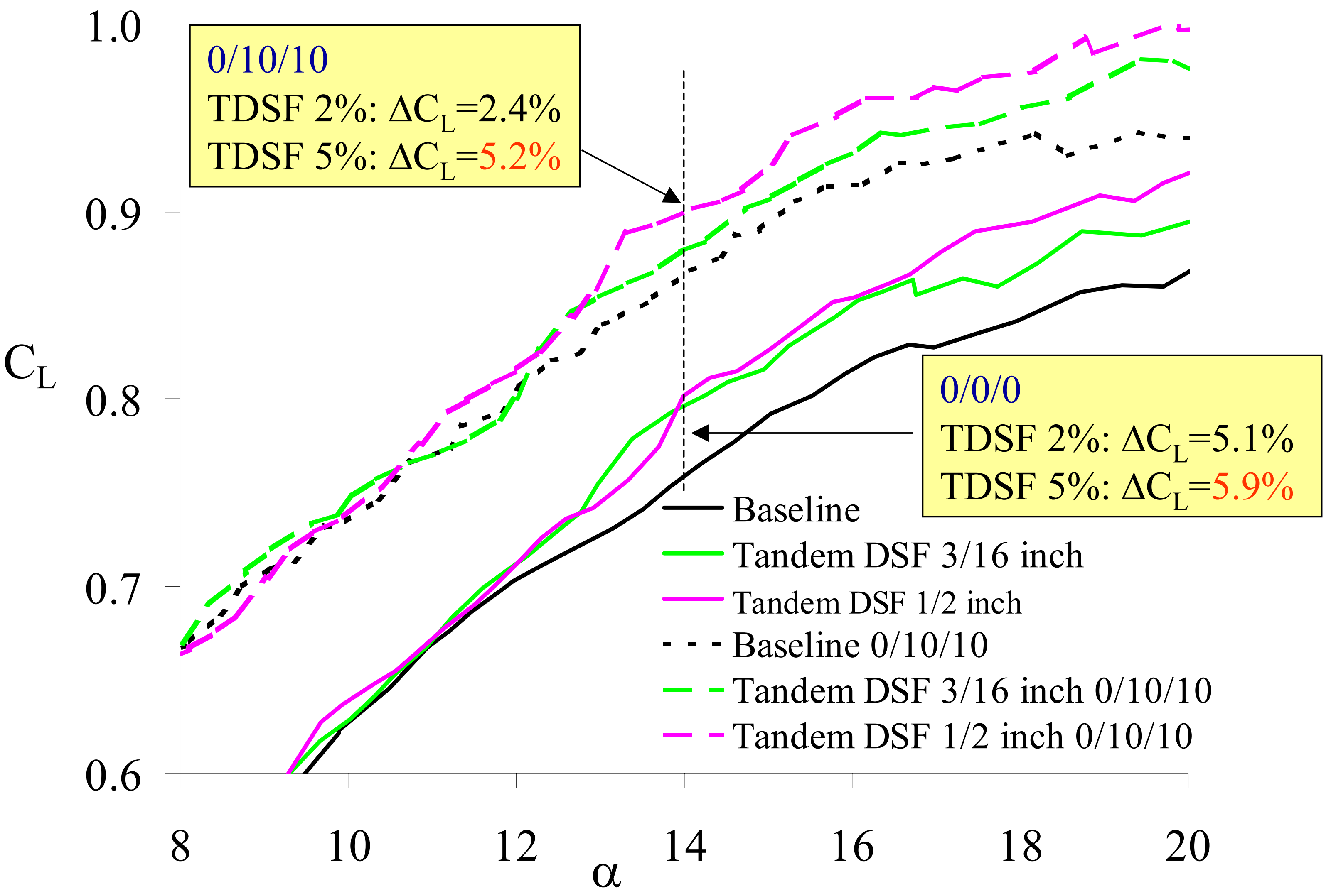
TDSF vs. TUSF: C_L vs. α



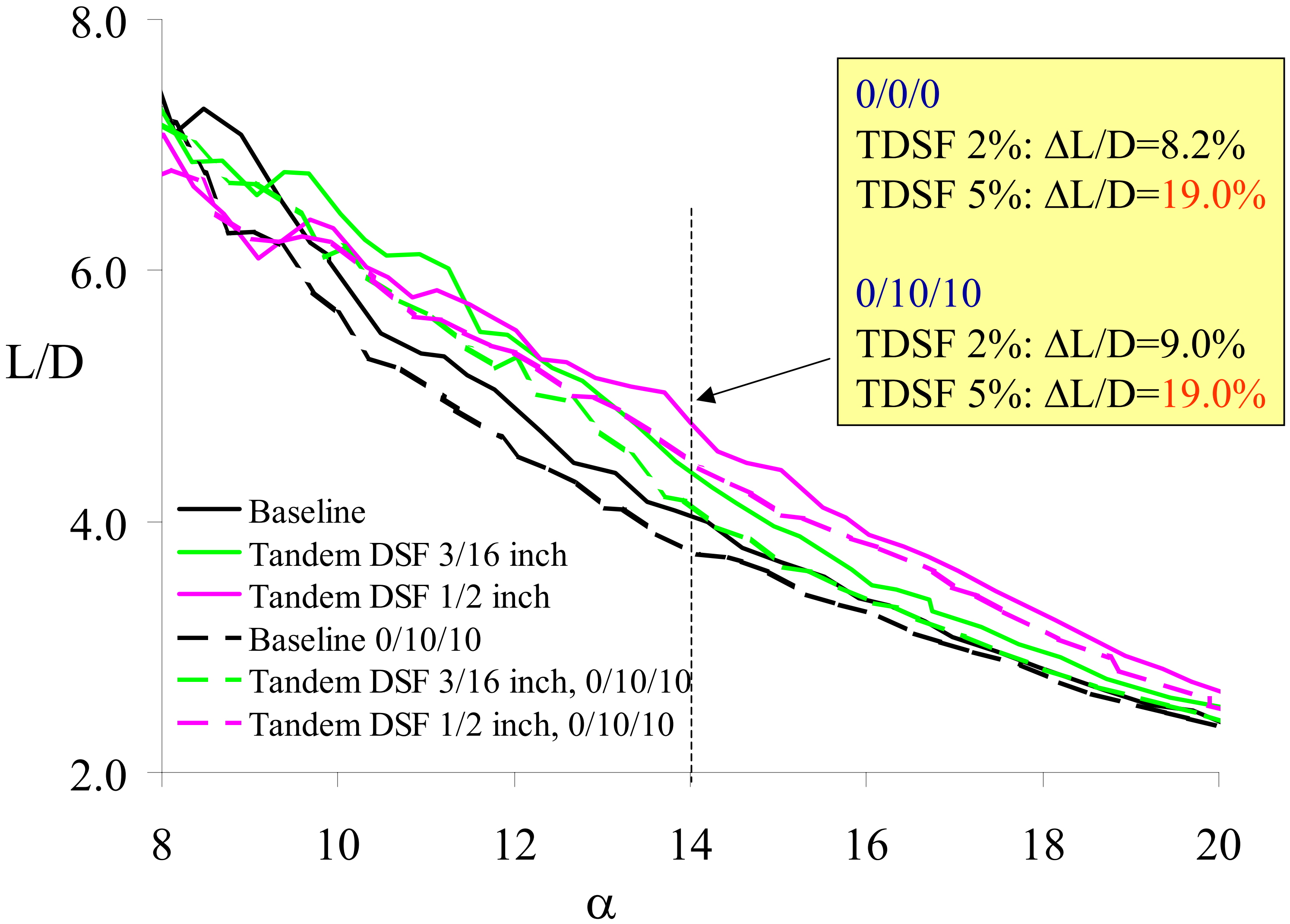
TDSF vs. TUSF: L/D vs. α



Height Effect: C_L vs. α



Height Effect: L/D vs. α



Conclusions

- **Single, Tandem, and Tandem In-Opposition DSF improved lift and L/D ratio**
- **Tandem DSF In-Opposition greatest increase in lift, Tandem DSF greatest increase in L/D ratio**
- **Delayed outer wing panel separation and vortex bursting**

Conclusions, cont.

- Serrations were effective in lift generation, detrimental to L/D ratio compared to USF
- DSF improved TEF performance
- Moving DSF closer to LE optimizes performance gains
- Increasing DSF height improved lift, greatly enhanced L/D ratio
- Unfortunately, does not eliminate LO penalty

Future Directions

- **Parametric study/understand flow physics:**
  - δ, spanwise length/location
  - Teeth/inch, serration height, tapered height?
  - Location: % MAC vs. % local c
  - Inter-DSF spacing, multiple DSF
  - Flow visualization of DSF/USF
- **Collaboration w/ USNA (Dr. Miklosovic)**
  - Multiple USF, Λ, δ, planform, LE radius
  - Joint paper planned
- **Collaboration w/ TTCP (US, UK, CAN, AUS)**
  - Little Re Effect on <u>Baseline</u> wing (DSTL 5m WT, July 2002 test)
  - Wing pressures of <u>Baseline</u> wing, to be analyzed

Contact

Terry Ghee
Advanced Aerodynamics Branch
NAVAIR, Code 4321
Building 2187, Suite 1320B
Patuxent River, MD 20670-1906, USA

301-342-8536
301-342-8588 (FAX)
gheeta@navair.navy.mil