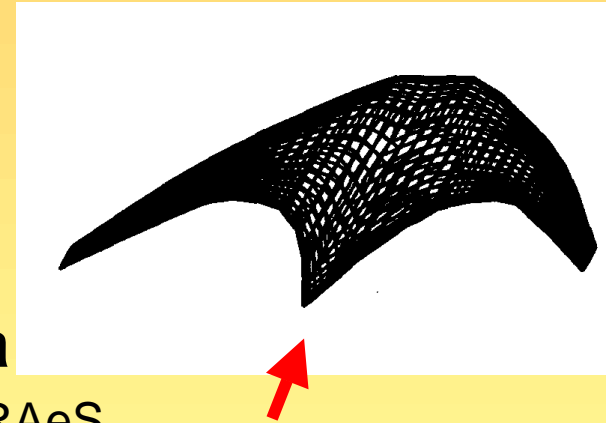
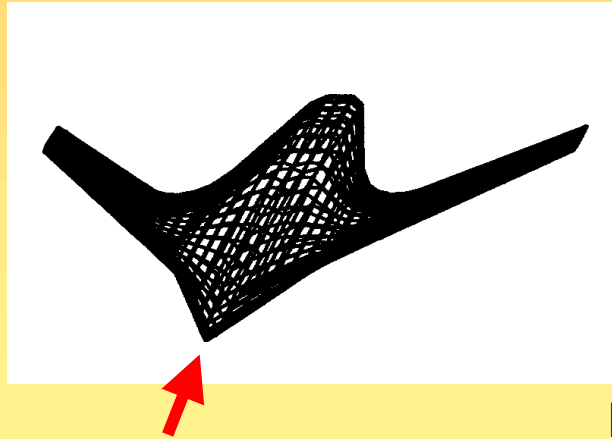


Nov 2002, Presentation UAV Workshop, Bath University

CONTROL ASPECTS OF FLYING WINGS WITH AFT - & FORWARD- SWEEP, Camber & Twist



Dr. R. K. Nangia

Bsc PhD CEng AFAIAA FRAeS
Nangia Aero Research Associates,
BRISTOL, UK.

**Copyright c: Nangia 2002,
Published by University of Bath with permission**

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 26 JUL 2004	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE Control Aspects Of Flying Wings With Aft - & Forward- Sweep, Camber & Twist		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) Nangia Aero Research Associates, BRISTOL, UK.		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
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	UU
			18. NUMBER OF PAGES 37
			19a. NAME OF RESPONSIBLE PERSON

ACKNOWLEDGEMENTS

- The work mentioned here is part of in-house R & D activities.
- Have pleasure in acknowledging helpful technical discussions with Mr. Les Hyde, Mr. John Hall & Dr. Mike Palmer.
- Lastly it should be mentioned that any opinions expressed are those of the author.

Introduction

- Revival of Interest in Flying wings, Military & Civil
- More Efficient ? More “Twitchy”
- Northrop B-2 & McDonnell Douglas (Boeing) Studies
- Some Commonality, Apart from STEALTH
- Short Moment arms & Low Inertia in Pitch

- Design for Well Behaved Pitch behaviour at all speeds & Cross-wind ability
- Intake, Propulsion Integration varies with Application

A Northrop B-2 Spirit bomber is shown in flight from a high-angle perspective, flying over a blue ocean with white clouds. The aircraft's dark, stealthy surface and unique flying wing design are clearly visible. Two light blue circles are overlaid on the image: one on the left wing and one in the center fuselage area.

No Winglets

No Fins

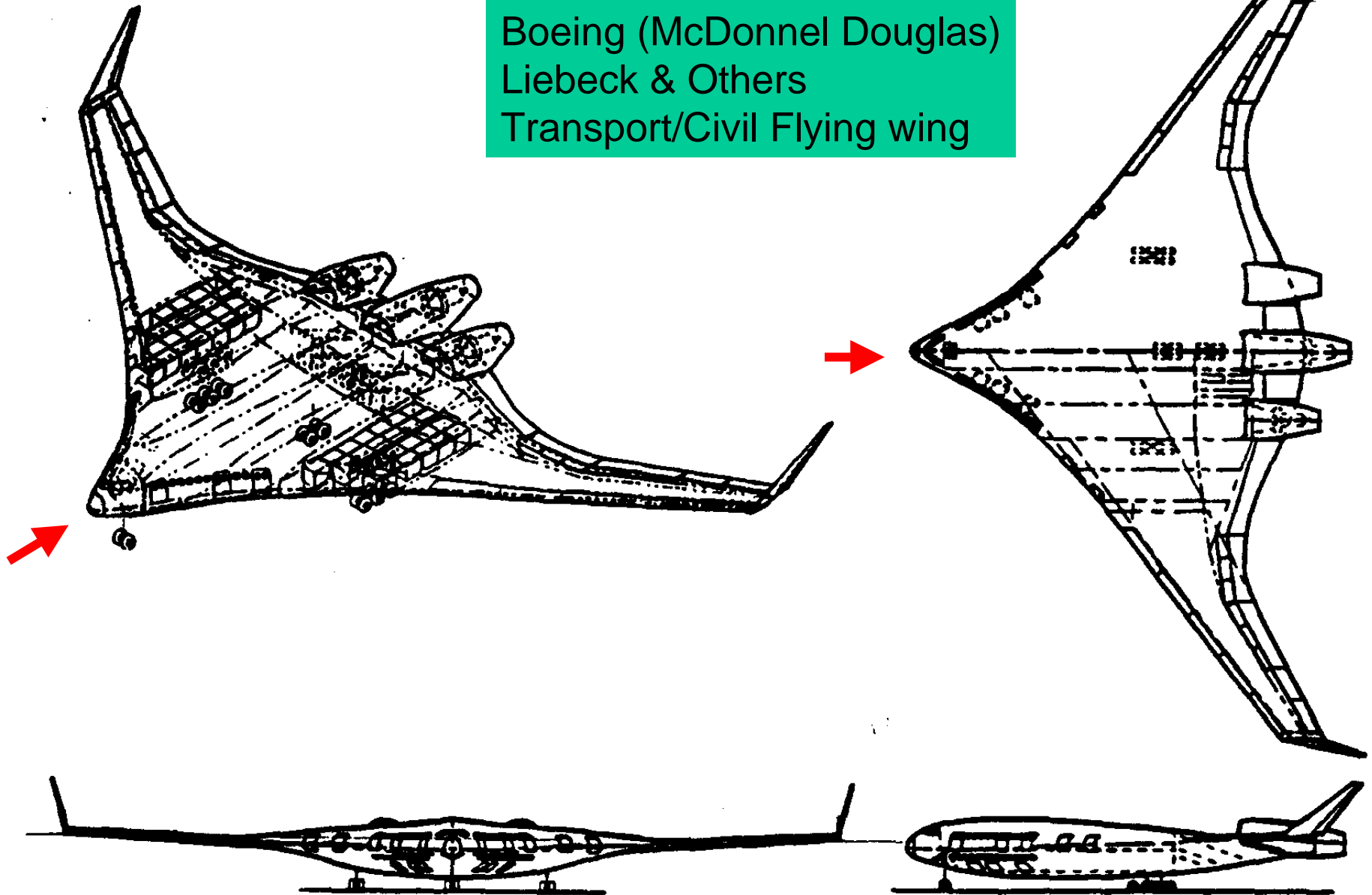
Northrop B-2, Essentially Optimised for Cruise



Military Flying Wings

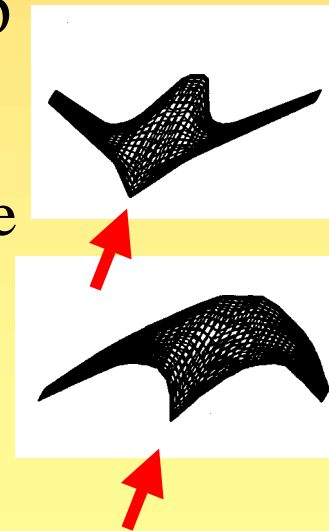


Boeing (McDonnell Douglas)
Liebeck & Others
Transport/Civil Flying wing



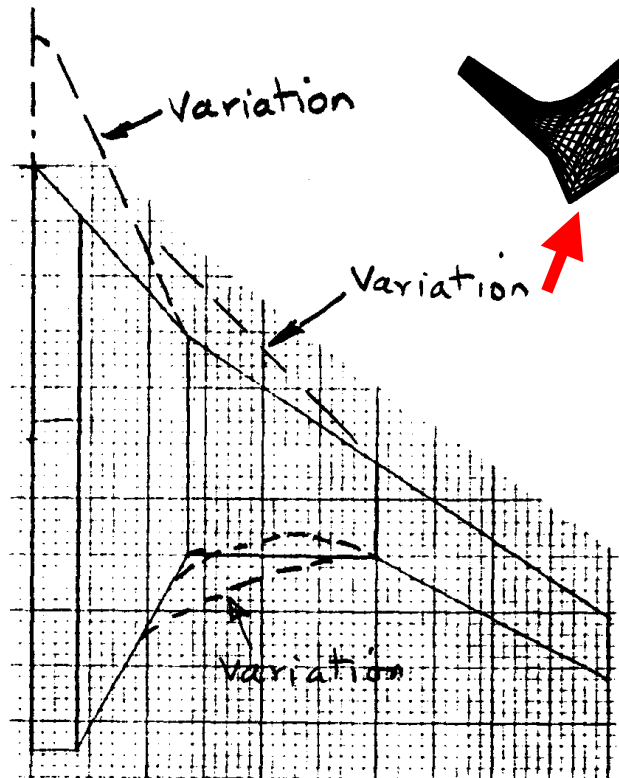
This Presentation

- Based Originally from a Civil Viewpoint
- Flying Wings have:
- Special set of Different Constraints vs Conventional
- Consider Planforms Aft- & Forward- Sweep
- Stability & Control Important
 - Design of Camber & Twist, Mach no divergence
 - Low speed & high speed neutral points
 - Floor angle
- Address Lateral & Directional Issues
- Avenues for Further Work

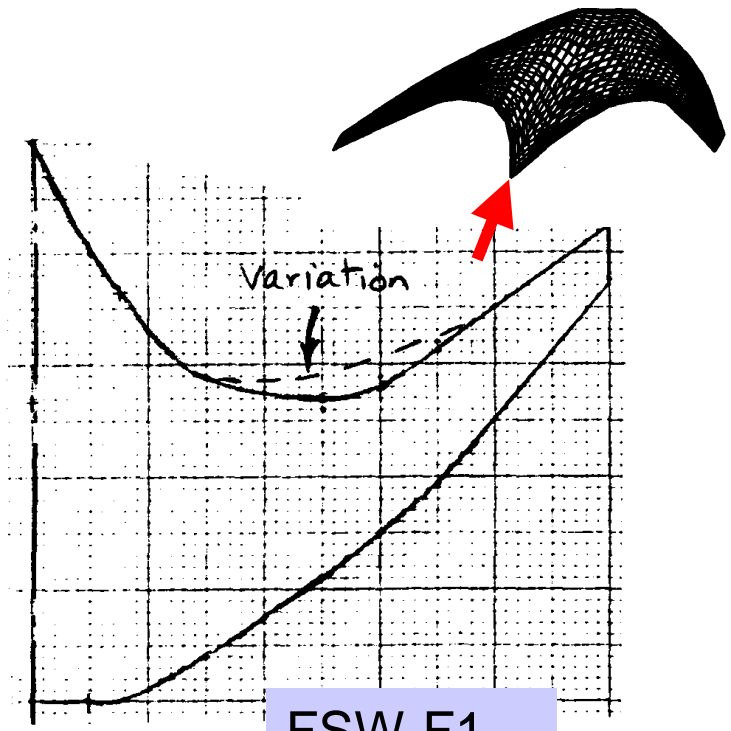


Approach: Subsonic Theory & Euler

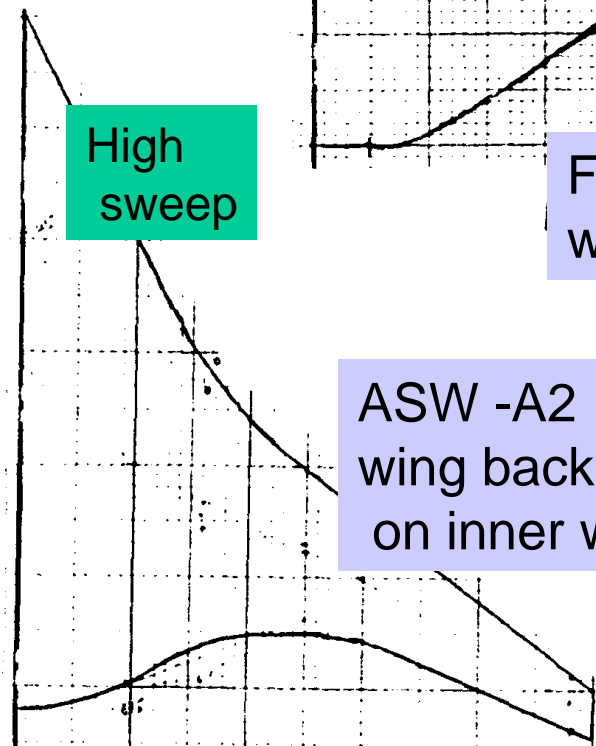
- Lifting Surface, Vortex Lattice Theory
 - first-Order Mach no Effects
- Attained Thrust & Vortex Estimates
- We tend to focus on S & C aspects first
 - longitudinal , Directional & Lateral Trim
 - Cruise & Field Performance
- Then detail design using Panel, CFD
 - Aerofoils, Shocks & Tailoring



ASW -A1
wing fw'd
on inner wing



FSW-F1
wing back



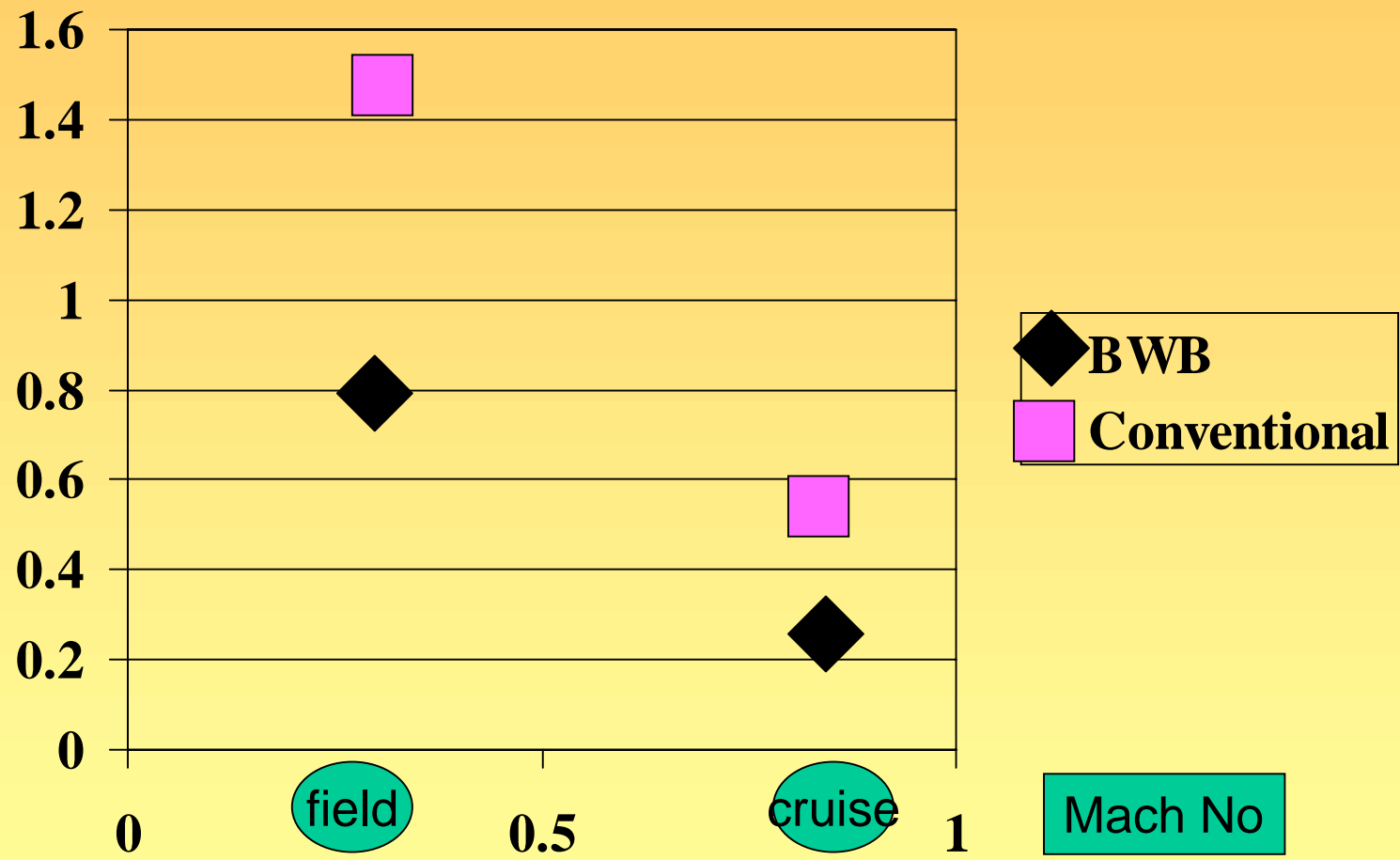
ASW -A2
wing back
on inner wing

High
sweep

Current Planform Studies
Many Feasible

CL

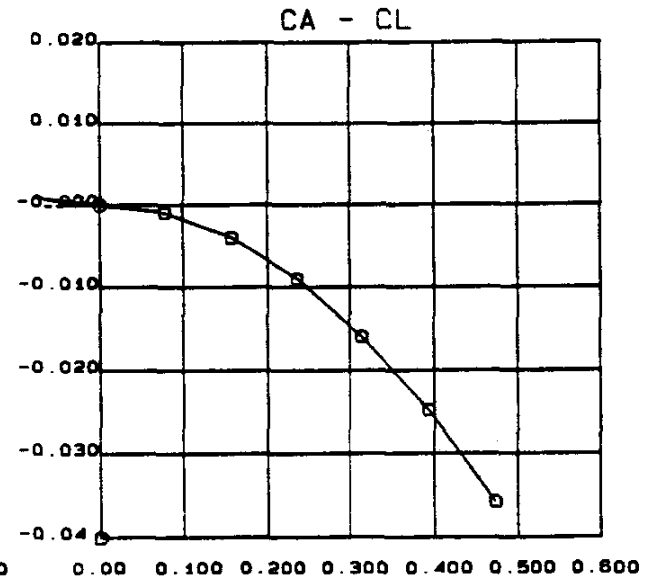
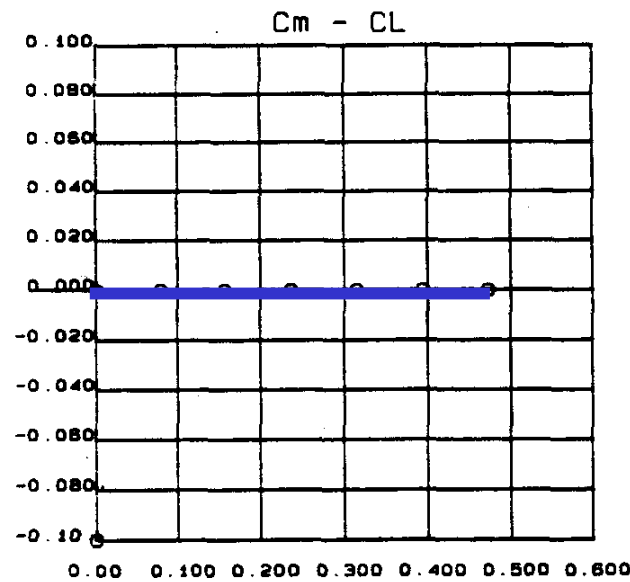
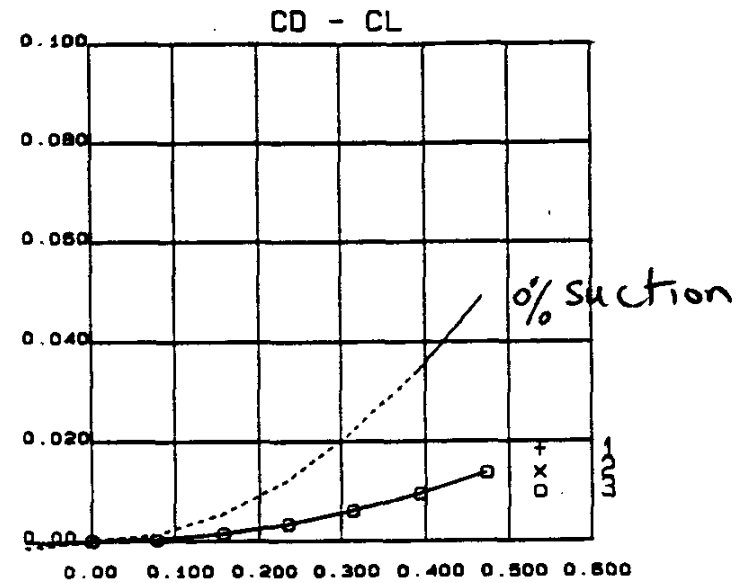
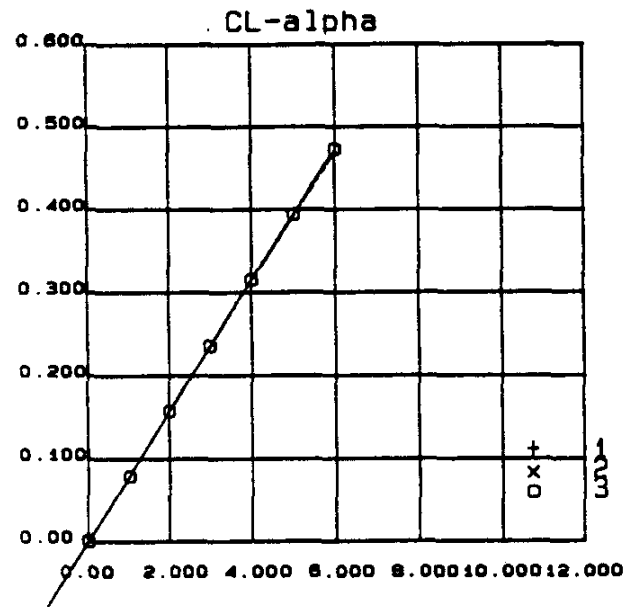
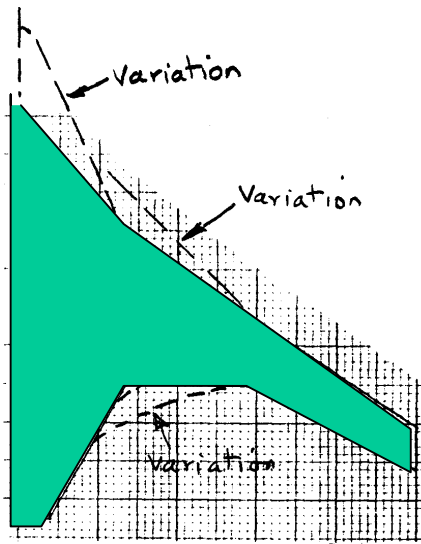
Design Envelope



Mach No

Practical “Highly” Swept Wings/portions at high lift

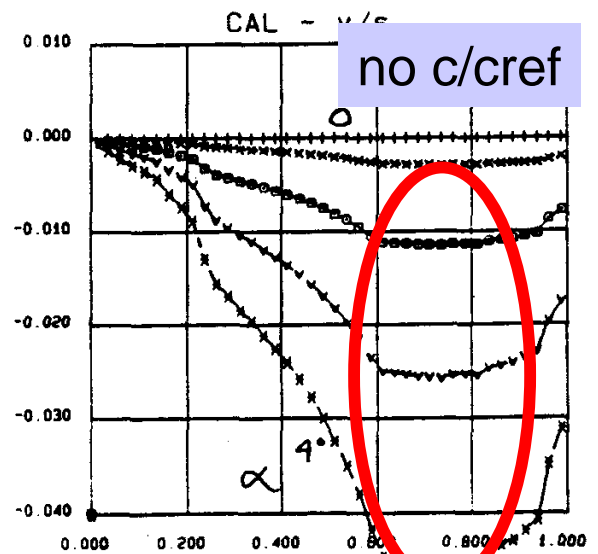
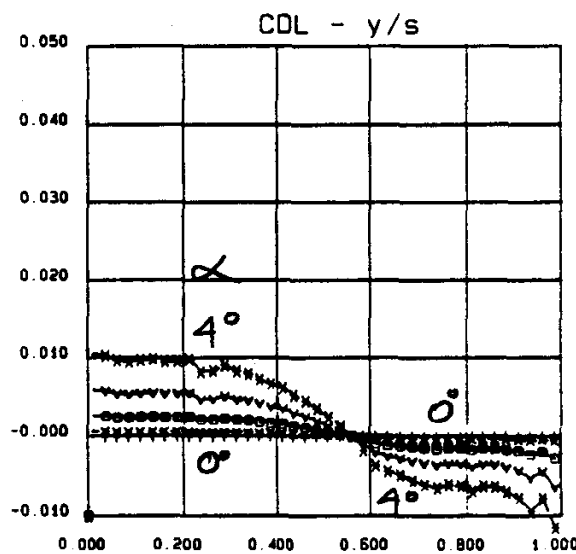
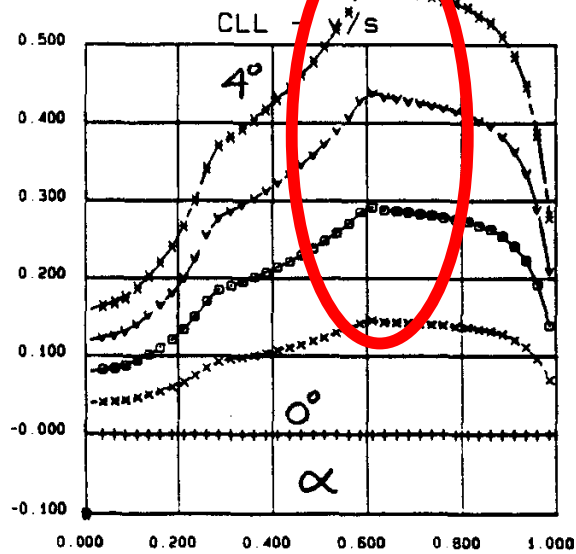
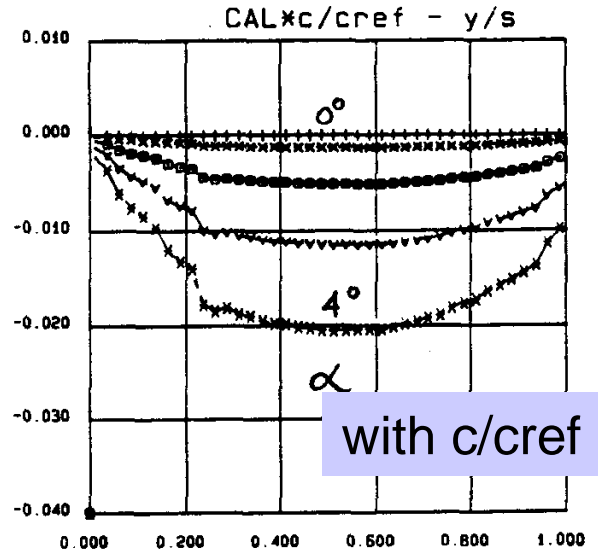
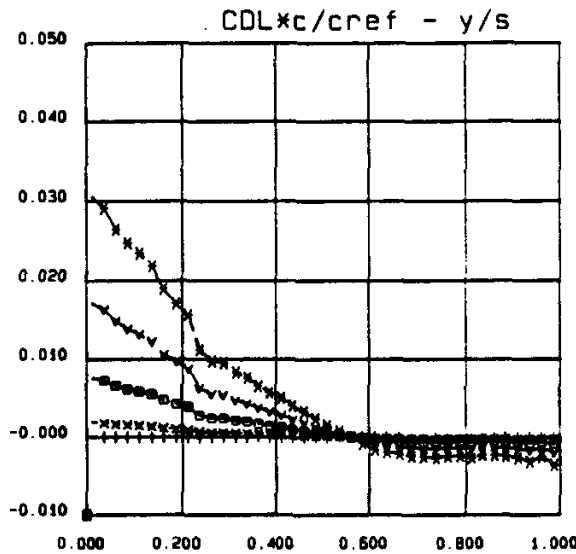
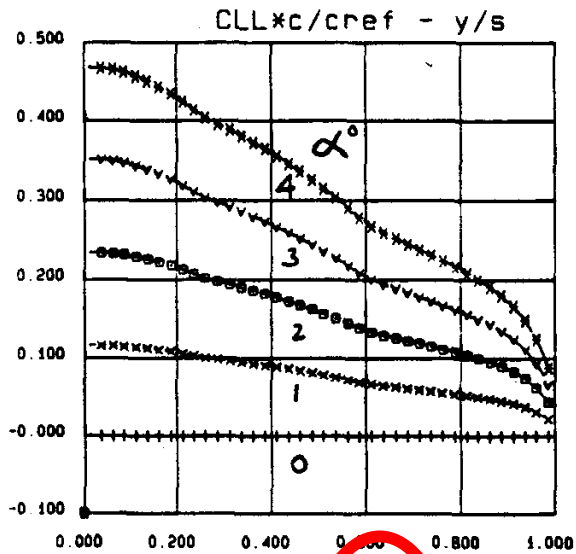
- Cranked LE poses difficulties
- local CL's high
- Use attached flows as far as possible (L/D)
- Use LE/TE devices, if possible !
- Need to understand Vortex Breakdown enough to control it or design around it
- Multiple vortex fields exist, “peeling” off



About
Neutral point

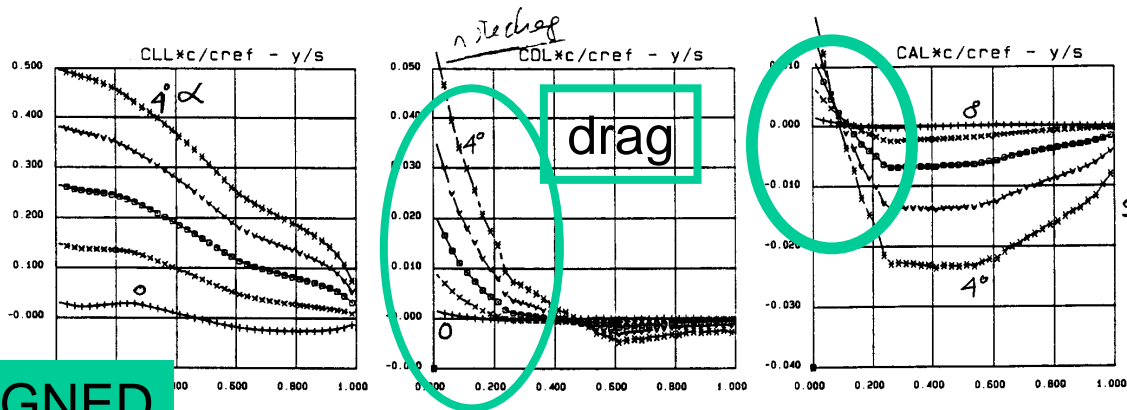
ASW -A1

PLANAR, FORCES & MOMENTS, Mach 0.8



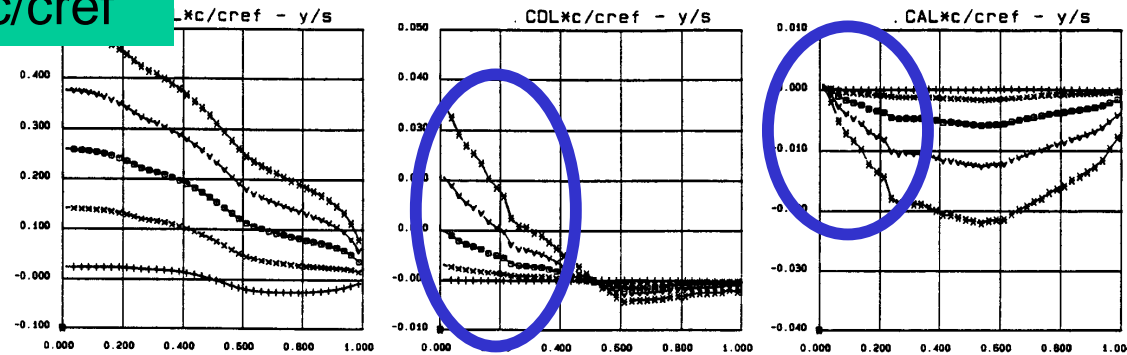
ASW -A1

PLANAR, SPANWISE LOADINGS WITH AOA VARIATION, LIFT, DRAG & AXIAL FORCE, Mach 0.8

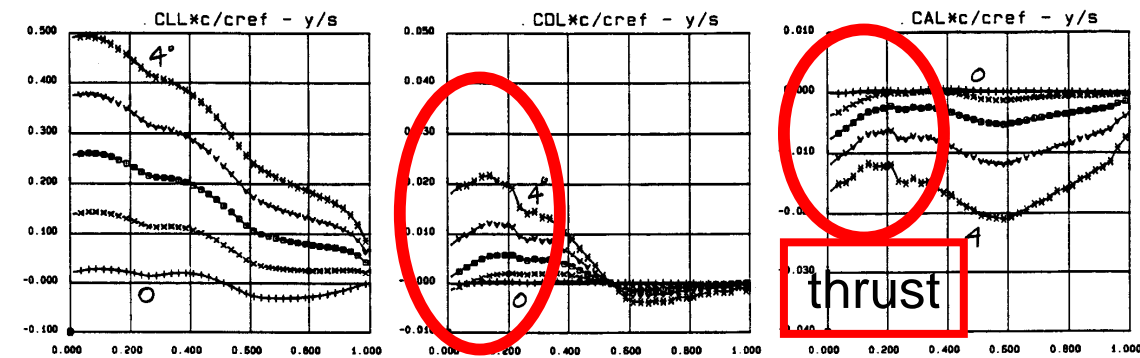


STABLE

DESIGNED
with c/c_{ref}

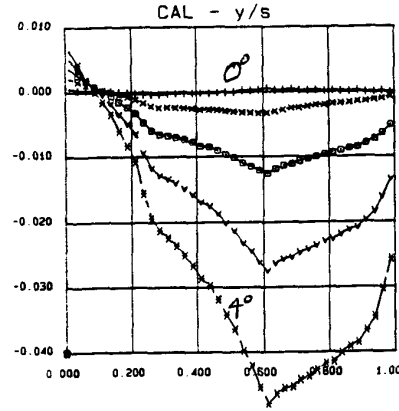
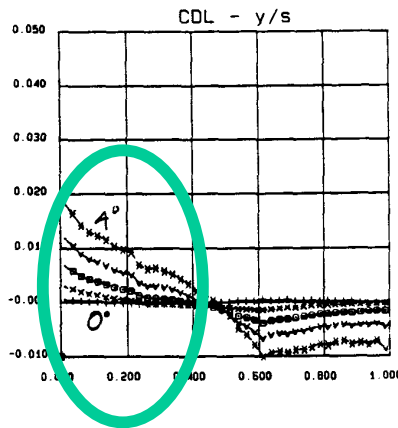
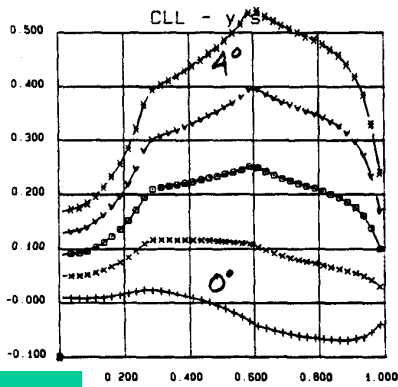


NEUTRAL



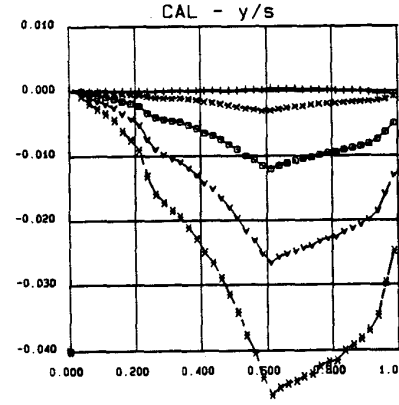
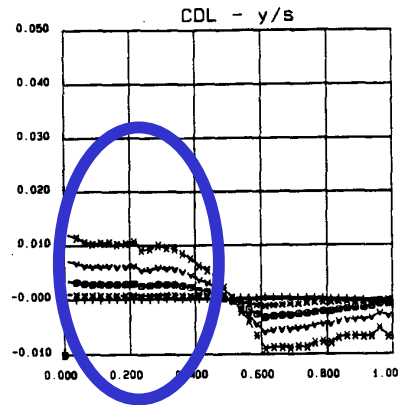
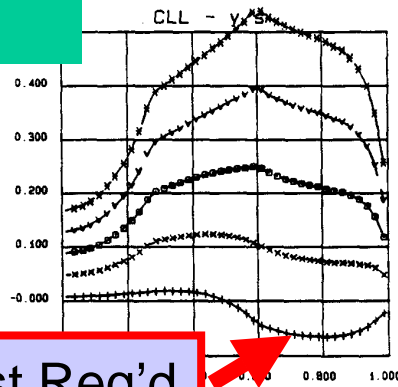
UNSTABLE

ASW -A1 PLANFORM A1, DESIGNED CAMBER, SPANWISE LOADINGS WITH c/c_{av} FACTOR, STATIC MARGIN VARIES, 10% c_{av} Stable, Neutral & 10% c_{av} Unstable, Mach 0.8



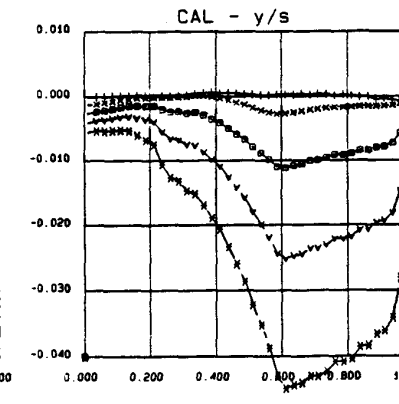
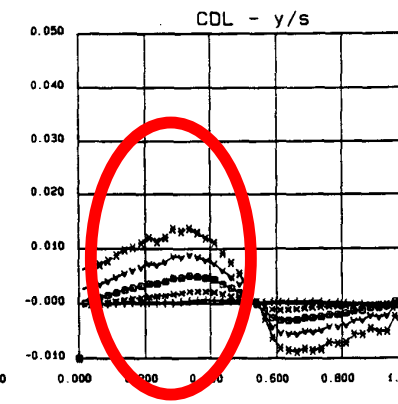
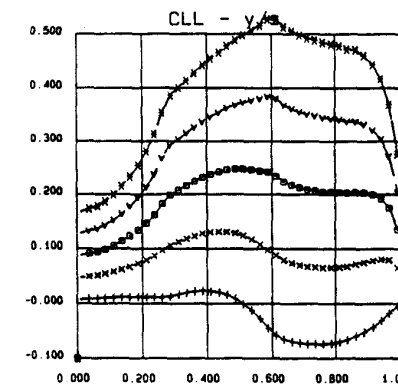
STABLE

DESIGNED
no c/c_{ref}



NEUTRAL

Note Twist Req'd



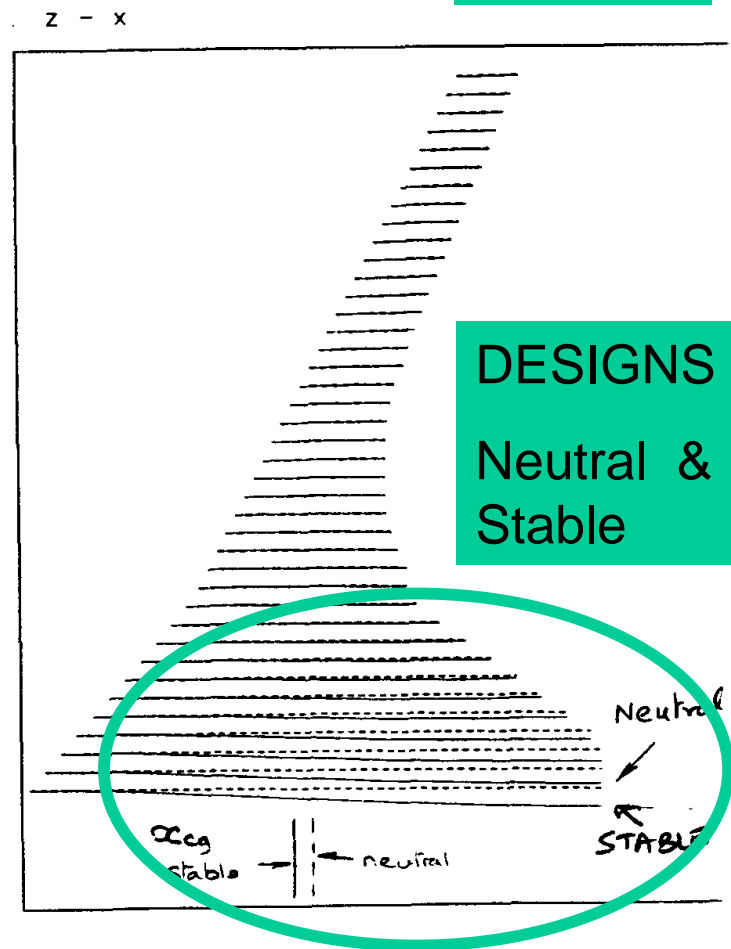
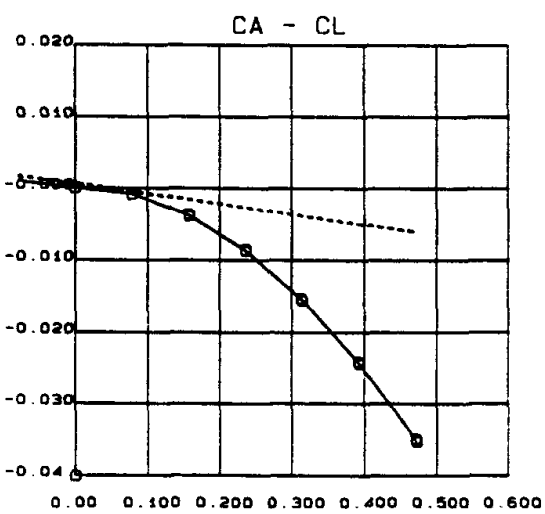
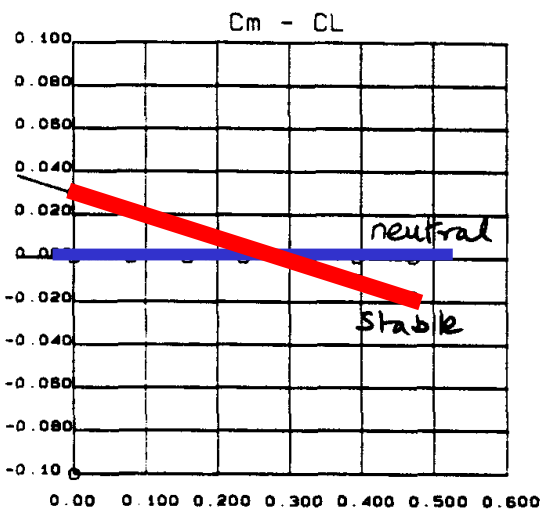
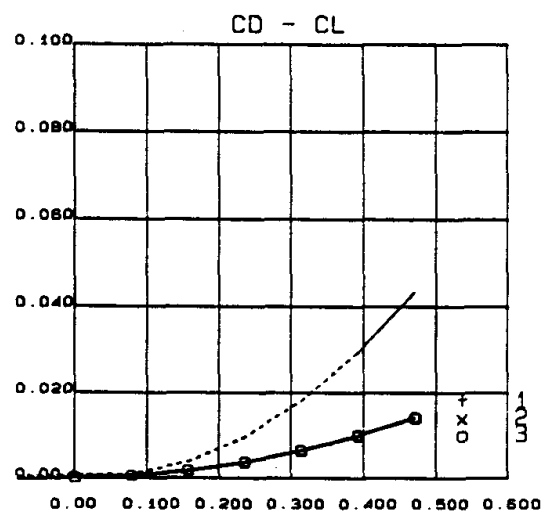
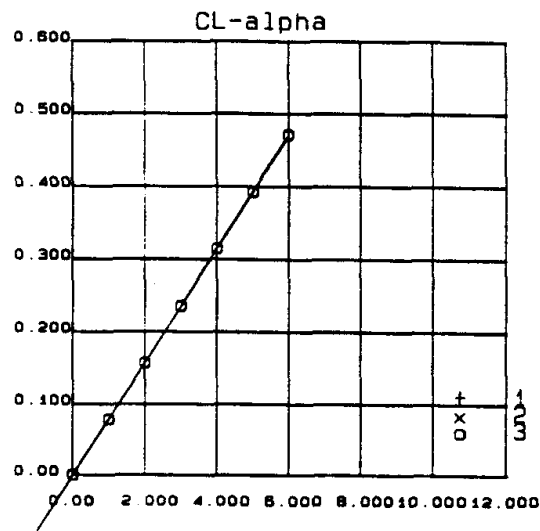
UNSTABLE

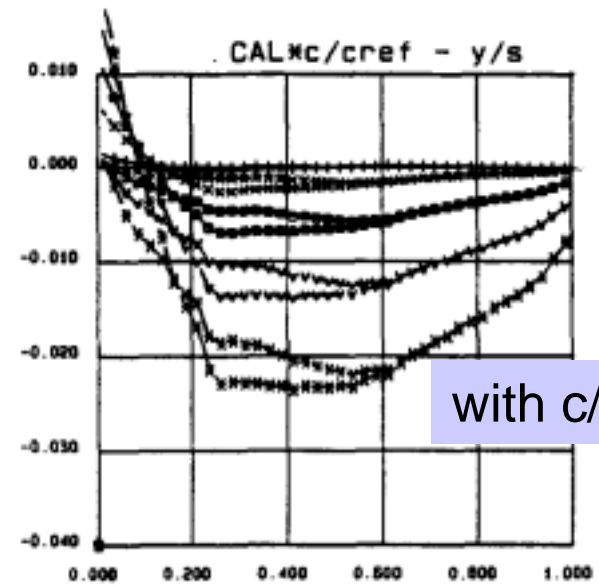
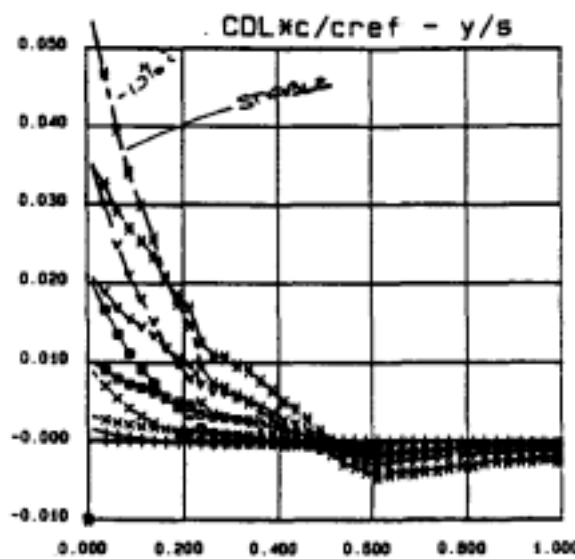
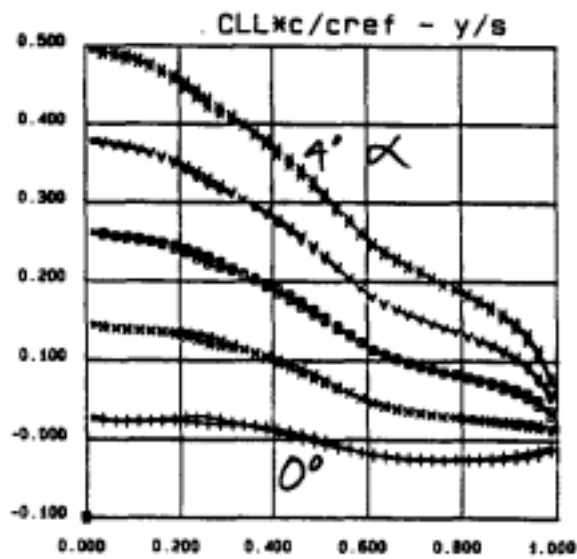
ASW -A1

FIG. 7. PLANFORM A1, DESIGNED CAMBER, SPANWISE LOADINGS WITHOUT c/c_{av} FACTOR, STATIC MARGIN VARIES, $10\%c_{av}$ Stable, Neutral & $10\% c_{av}$ Unstable, Mach 0.8

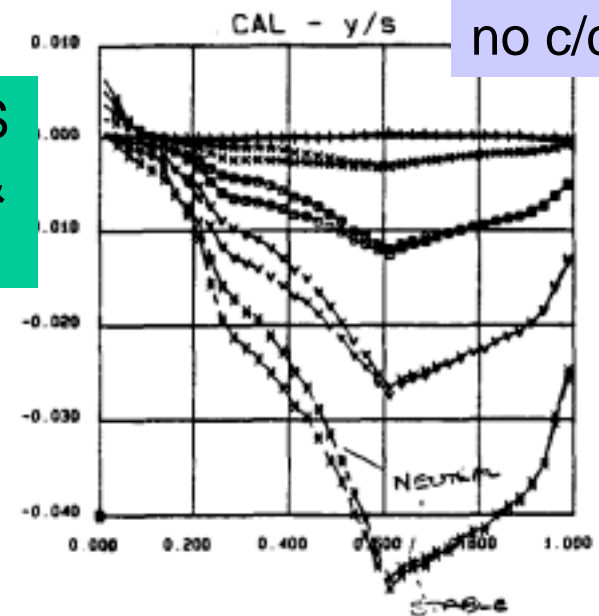
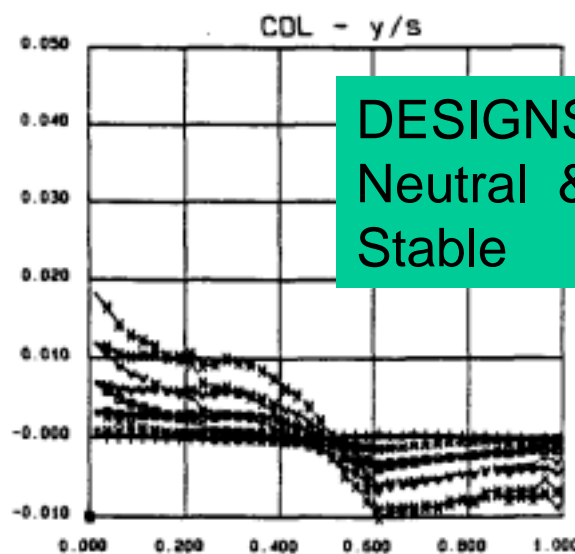
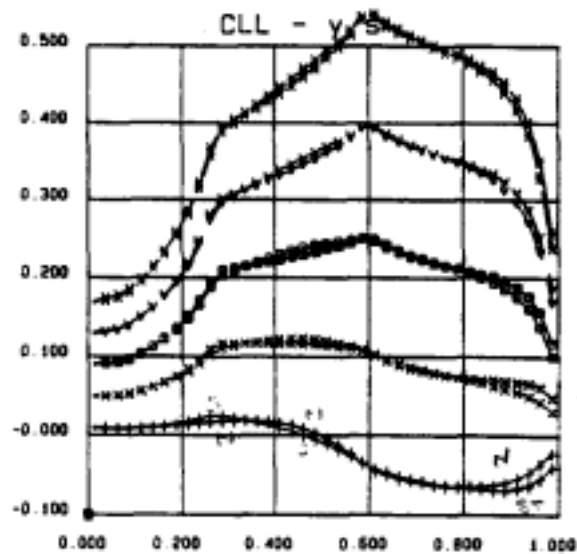
ASW -A1

DESIGNS
Neutral &
Stable





with c/cref

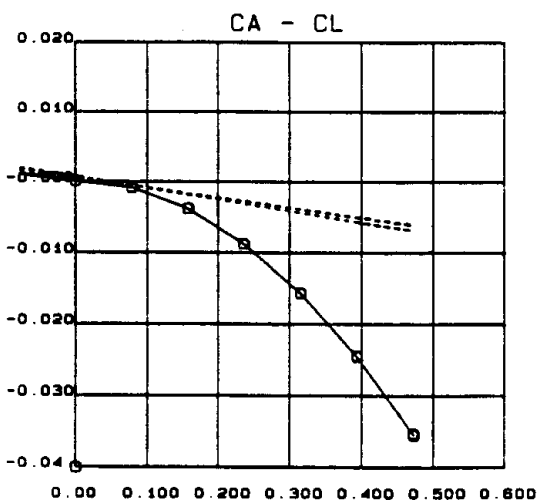
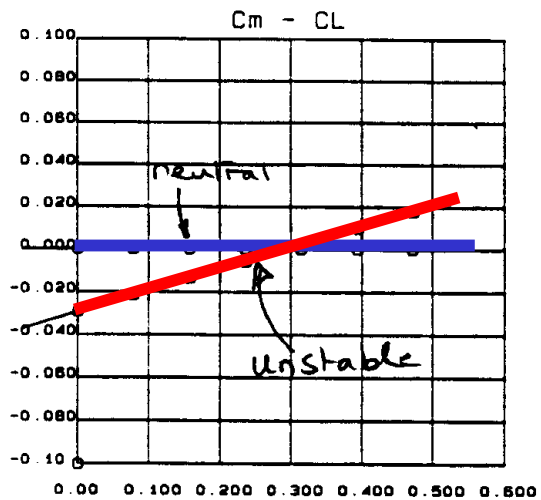
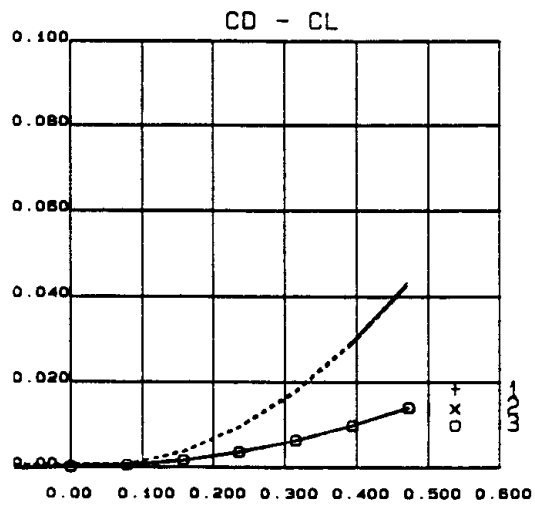
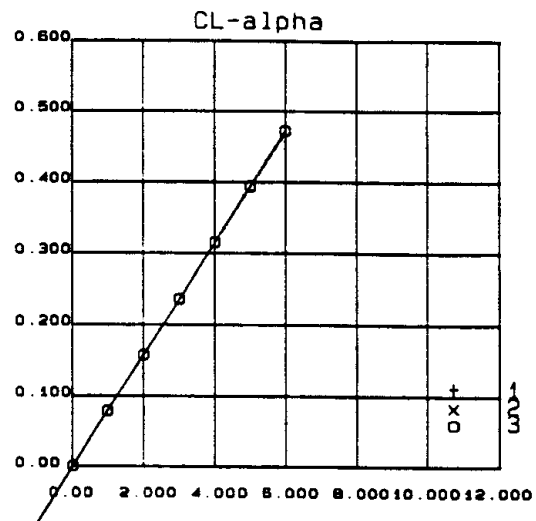


no c/cref

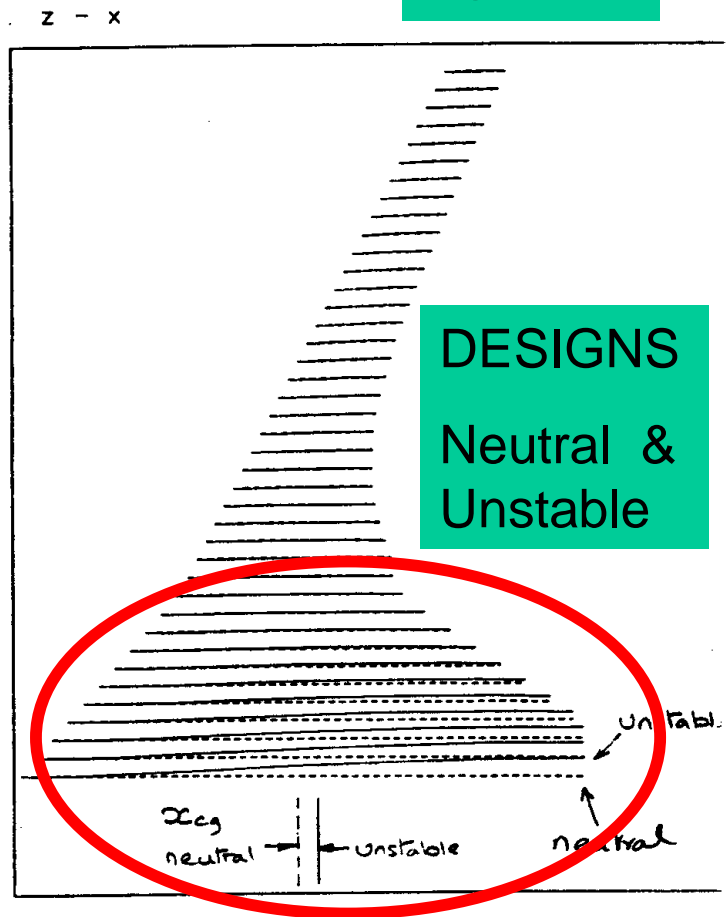
DESIGNS
Neutral &
Stable

ASW -A1

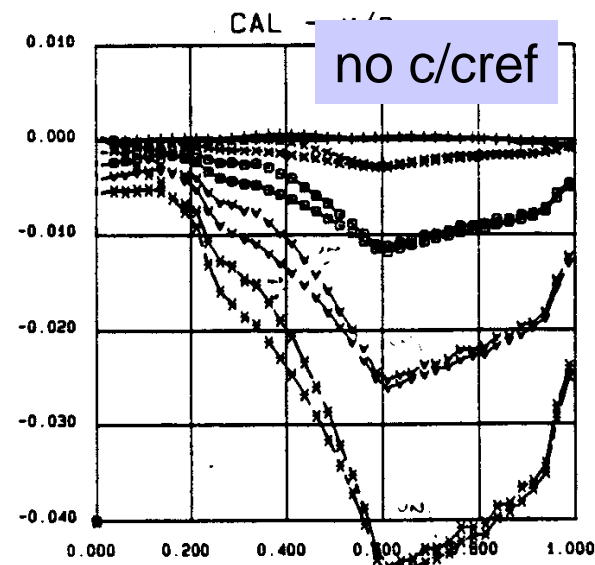
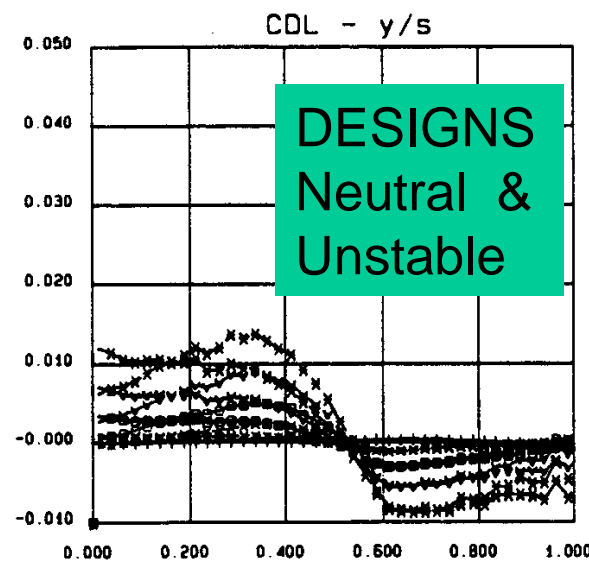
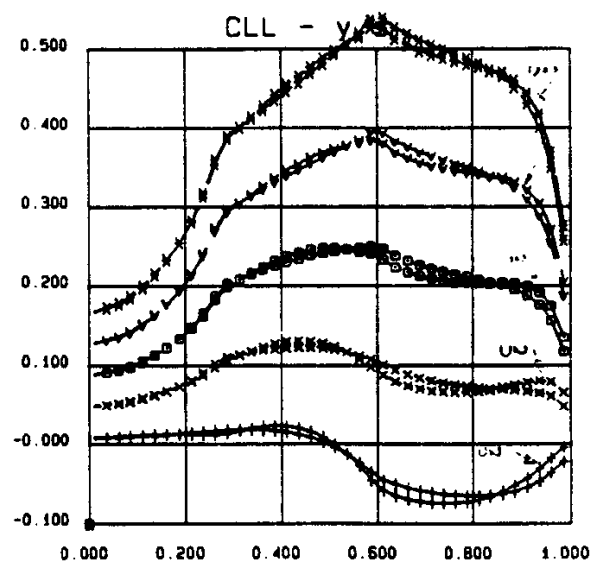
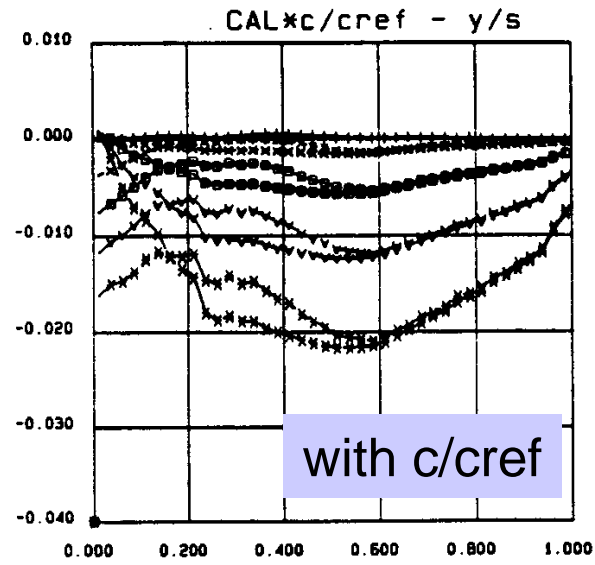
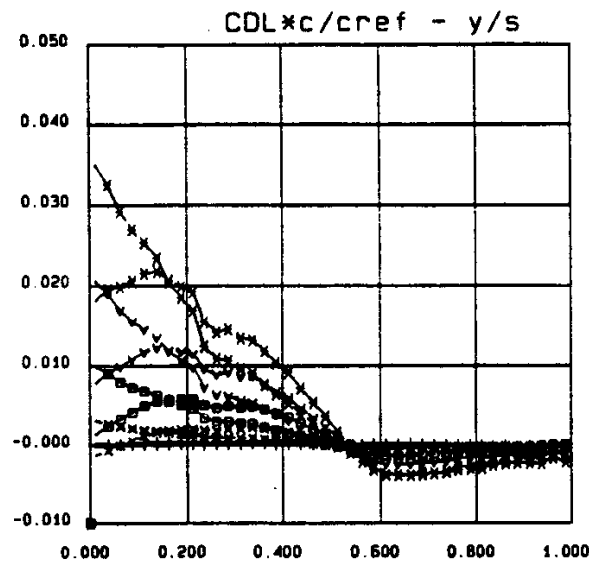
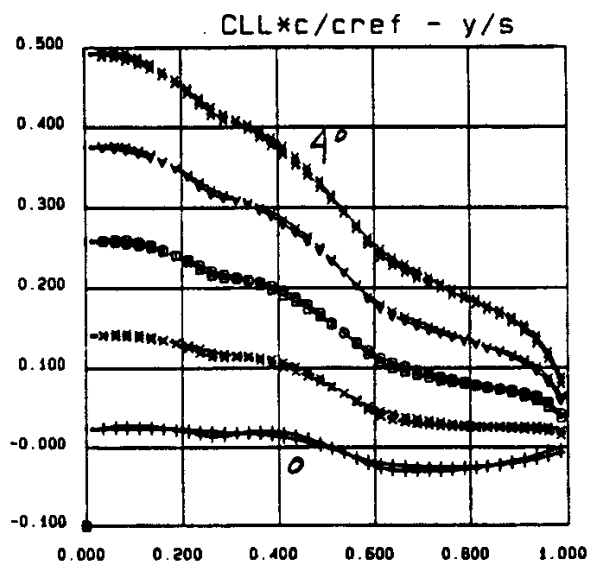
PLANFORM A1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10% c_{av} Stable, Neutral, Mach 0.8



ASW -A1



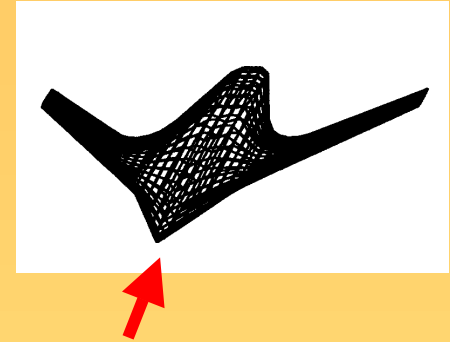
DESIGNS
Neutral &
Unstable



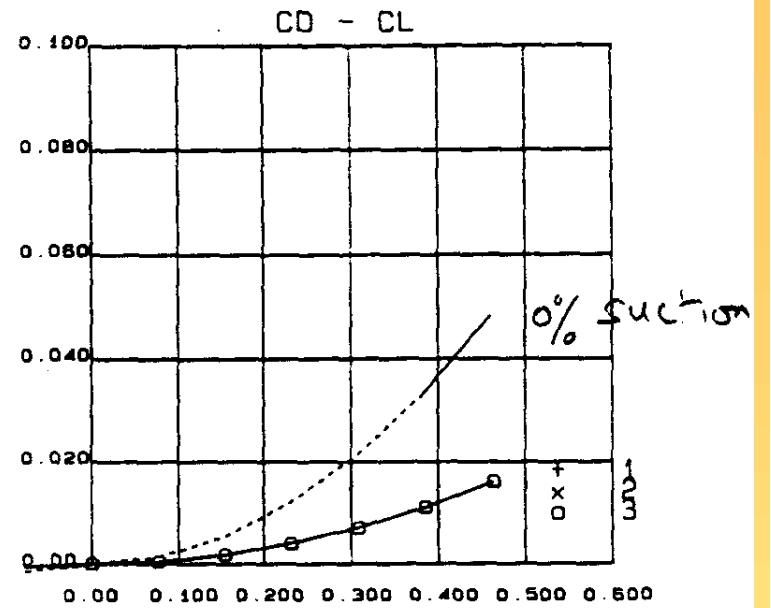
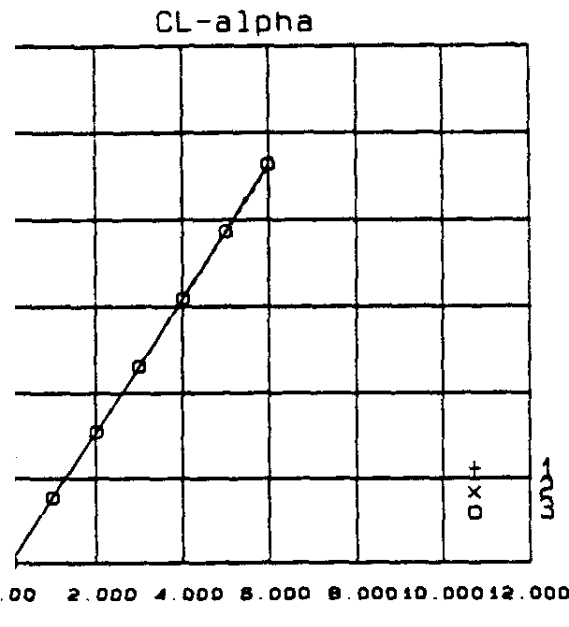
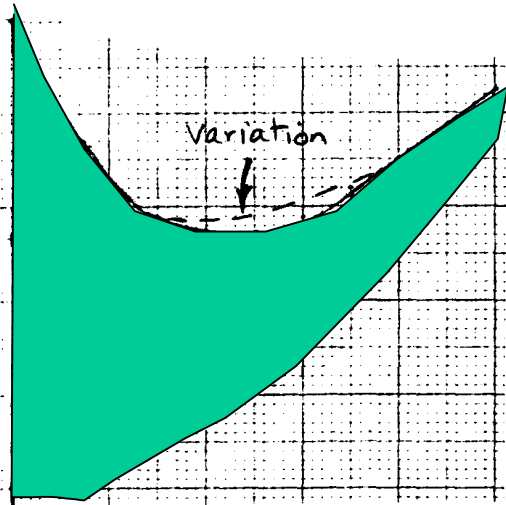
ASW -A1

PLANFORM A1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10% c_{av} Unstable, Neutral, Mach 0.8

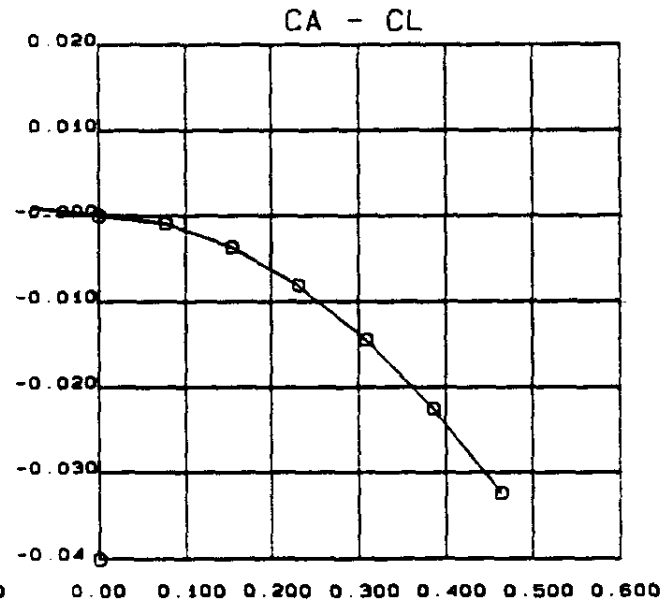
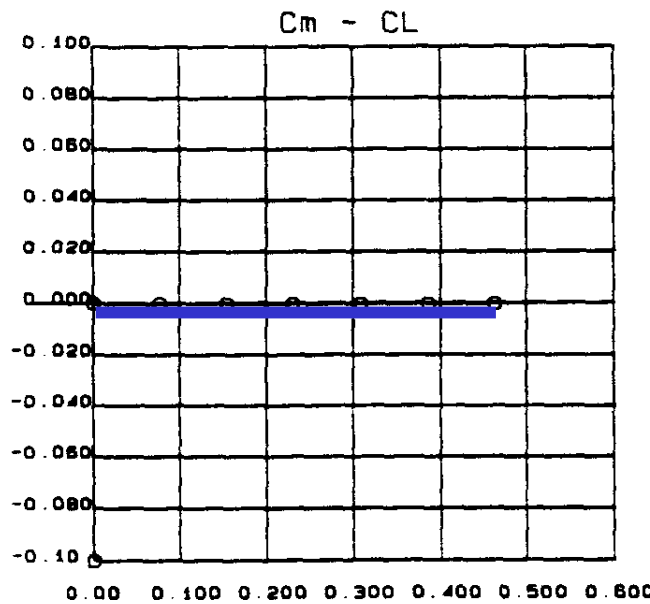
Longitudinal



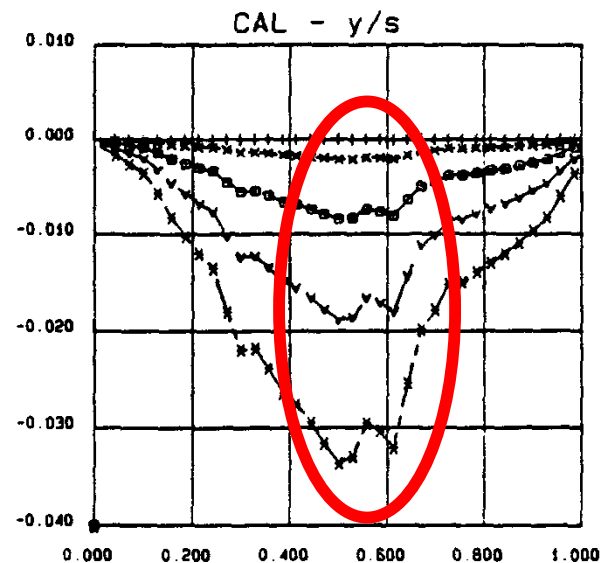
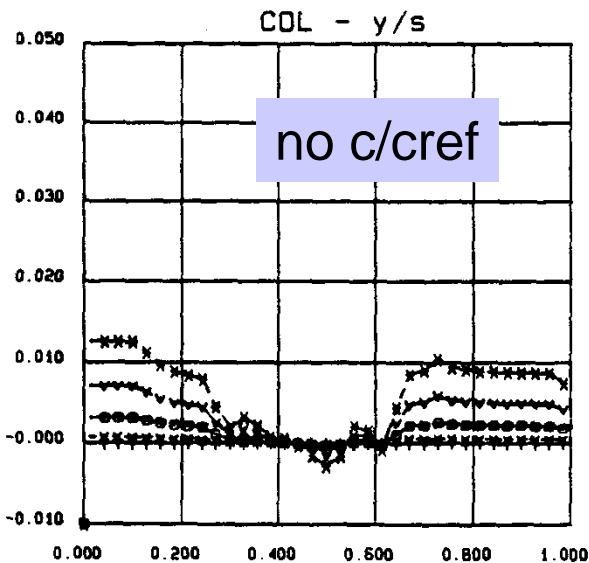
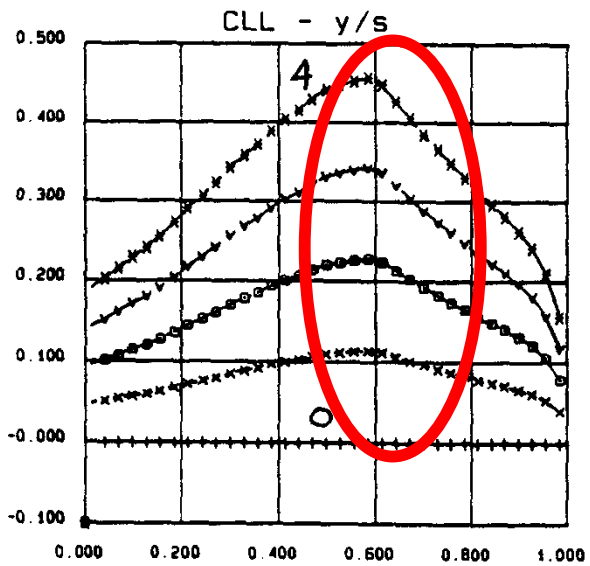
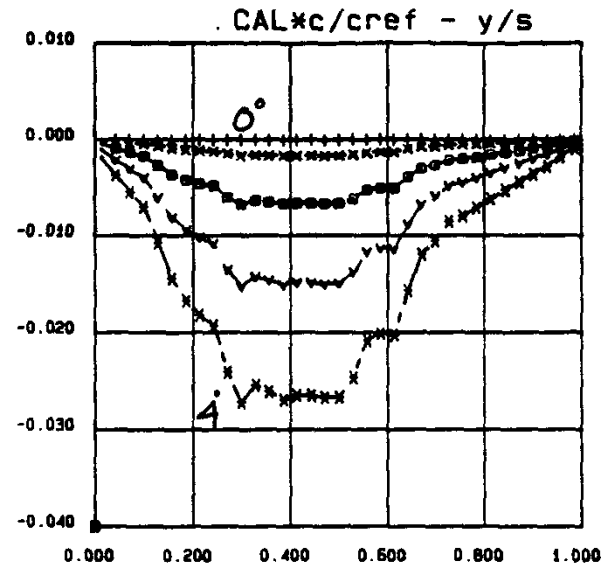
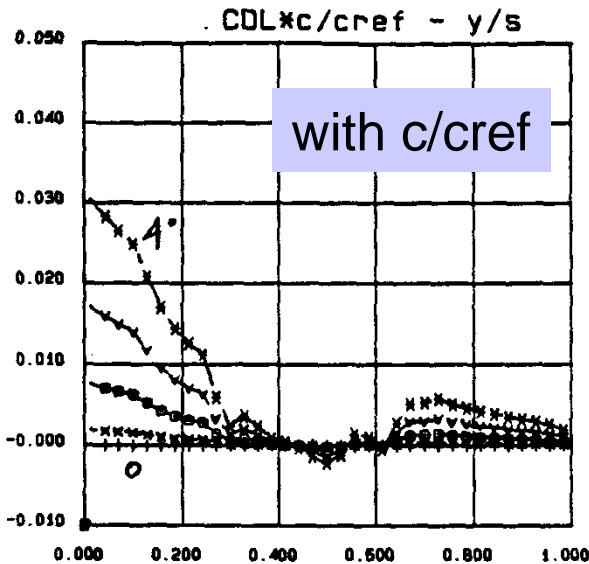
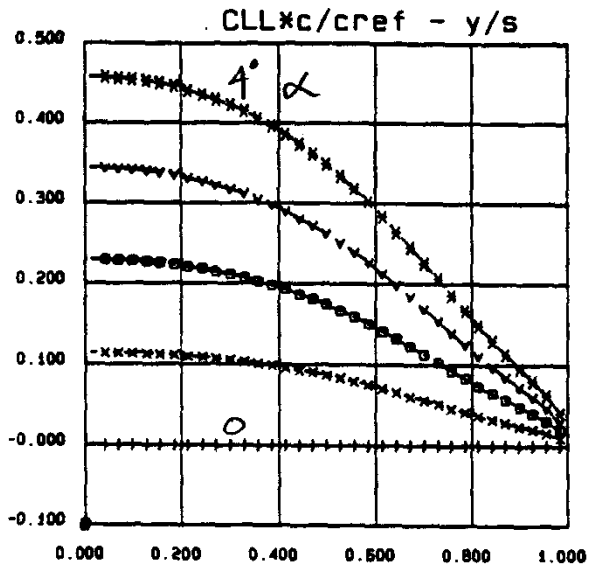
- Short Moment Arms, Low Pitch Inertia
- go for longer inner wing (fuselage !)
 - thickness important at root
- Cabin floor angle restriction
- Twist required, increases for stable flight
 - affects CD_0
- Neutral pt. shifts forward for low speed 3%, Trim!
- “armpit” control “fights” “tip” control, moment arms geometry cuts effectiveness by 1/2
- Need to continue Planform Work



About Neutral point



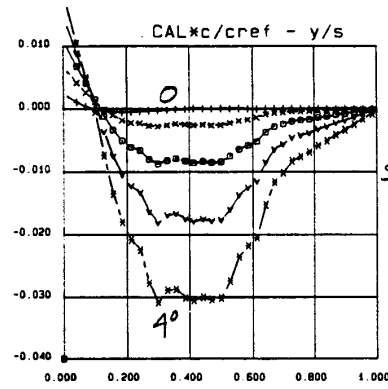
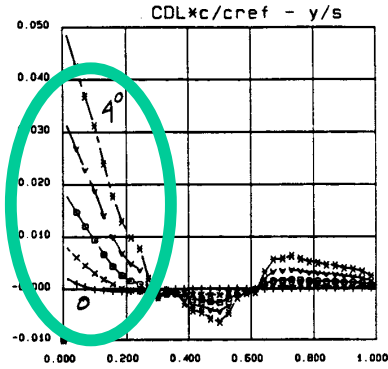
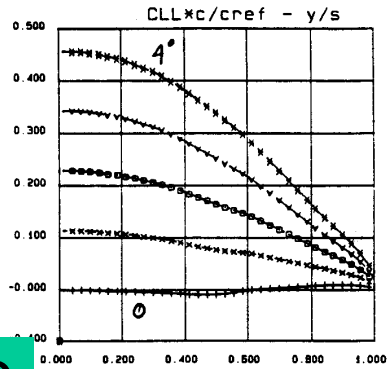
FSW -F1 , PLANAR, FORCES & MOMENTS, Mach 0.8



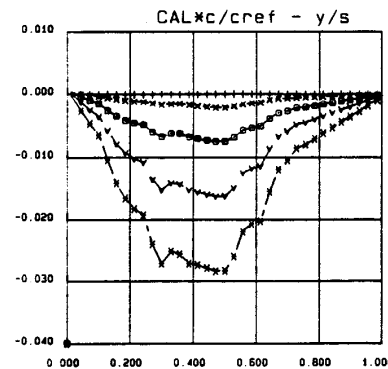
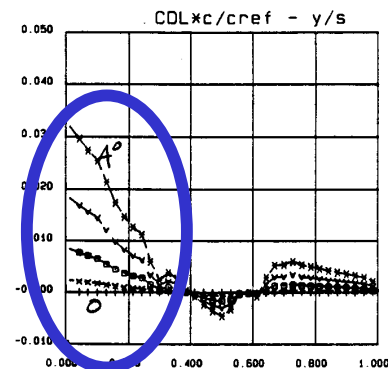
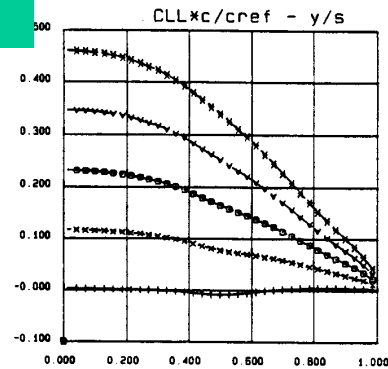
FSW -F1

PLANAR, SPANWISE LOADINGS WITH AOA VARIATION, LIFT, DRAG & AXIAL FORCE, Mach 0.8

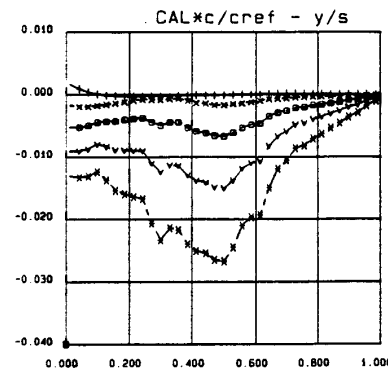
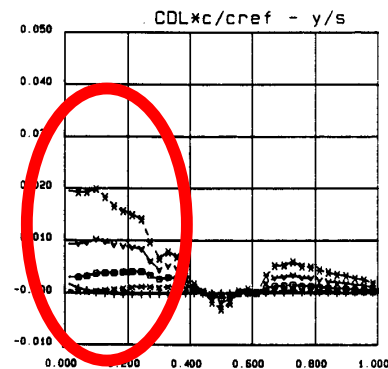
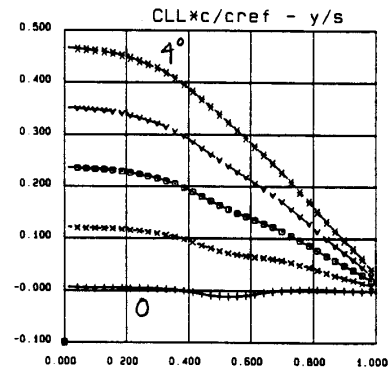
DESIGNED
with c/c_{ref}



STABLE



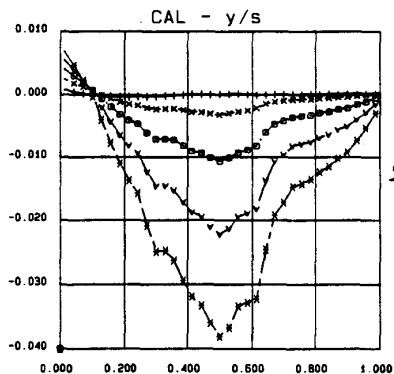
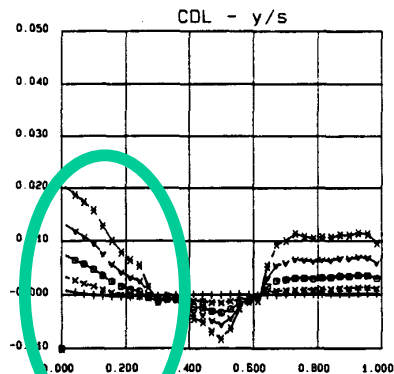
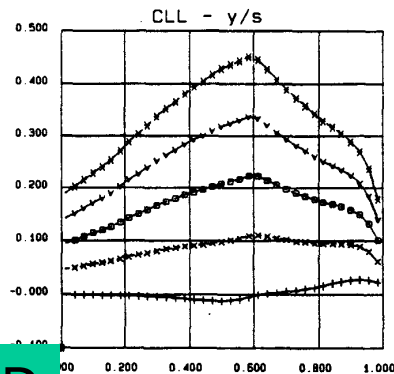
NEUTRAL



UNSTABLE

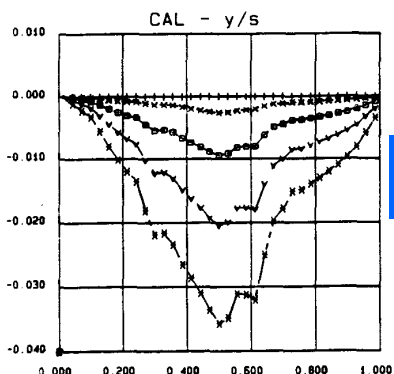
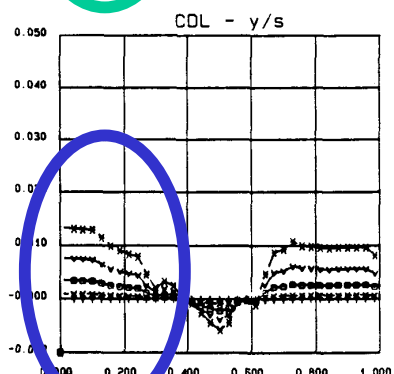
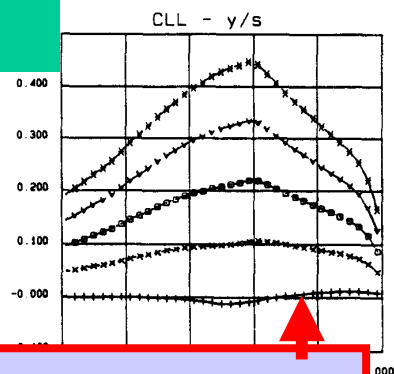
FSW -F1

PLANFORM F1, DESIGNED CAMBER, SPANWISE LOADINGS WITH c/c_{av} FACTOR, STATIC MARGIN VARIES, 10% c_{av} Stable, Neutral & 10% c_{av} Unstable, Mach 0.8



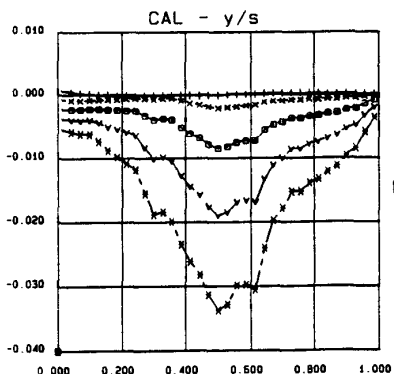
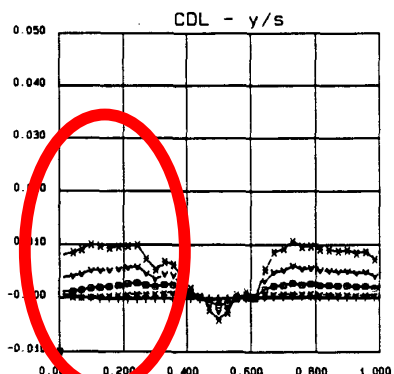
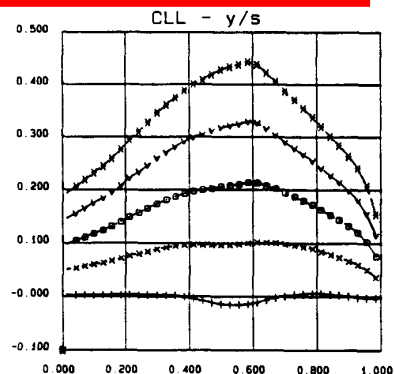
STABLE

DESIGNED
no c/c_{ref}



NEUTRAL

Note Lack of Twist Req'd



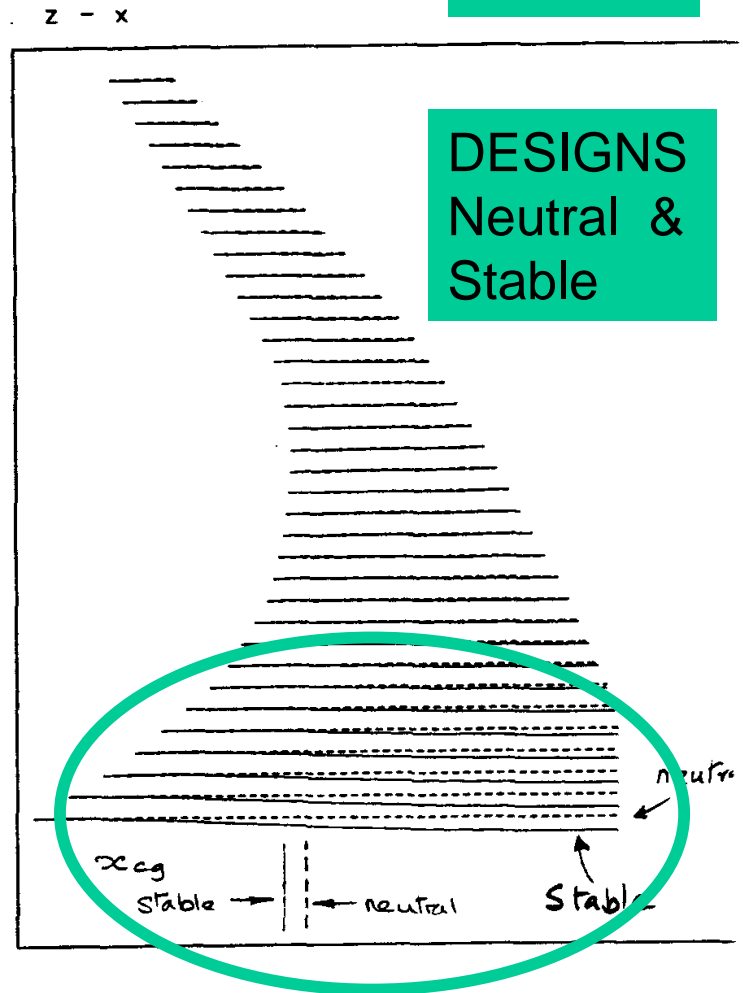
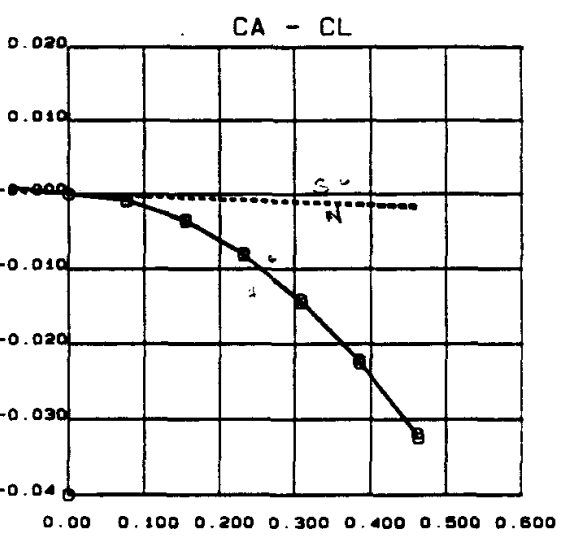
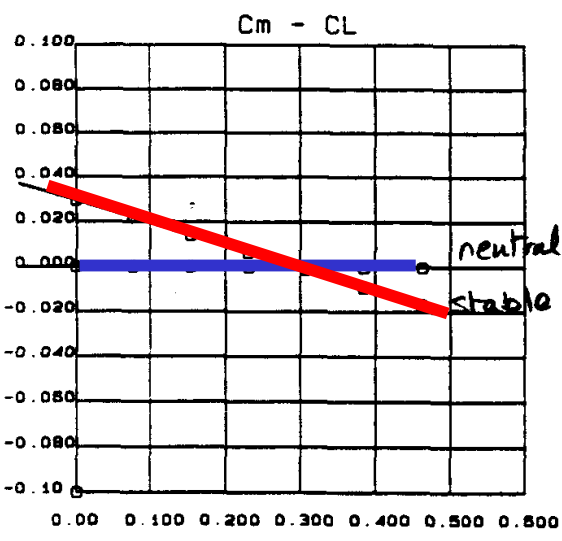
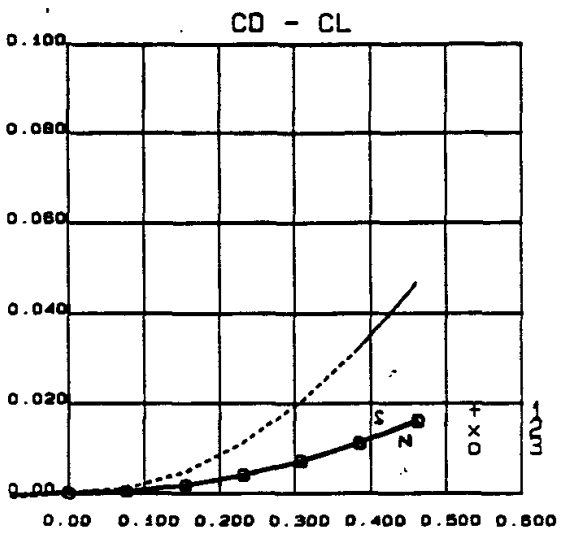
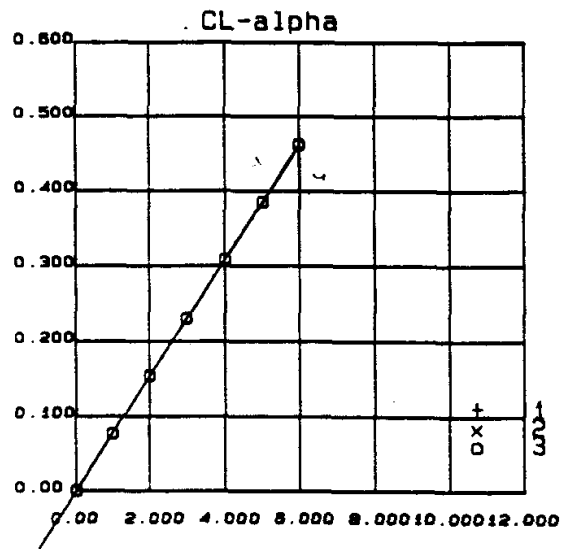
UNSTABLE

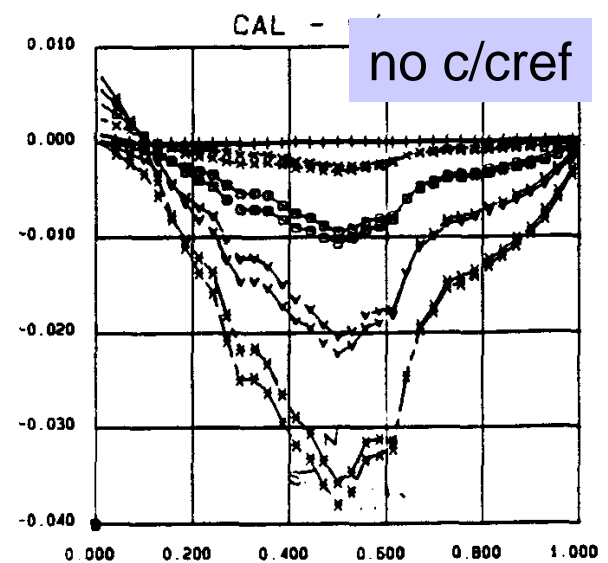
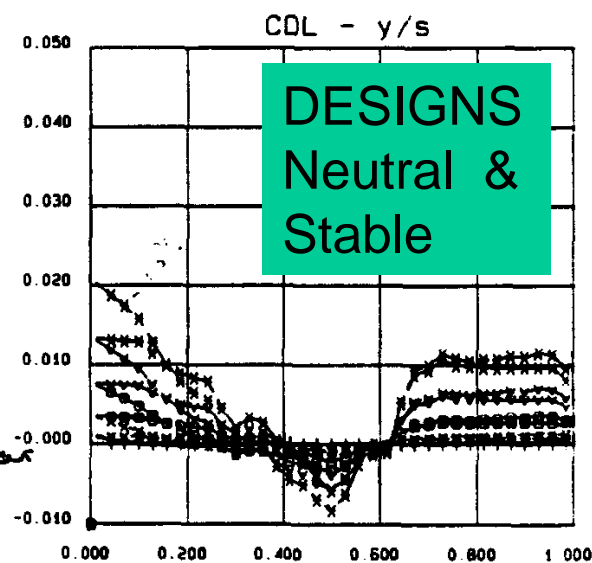
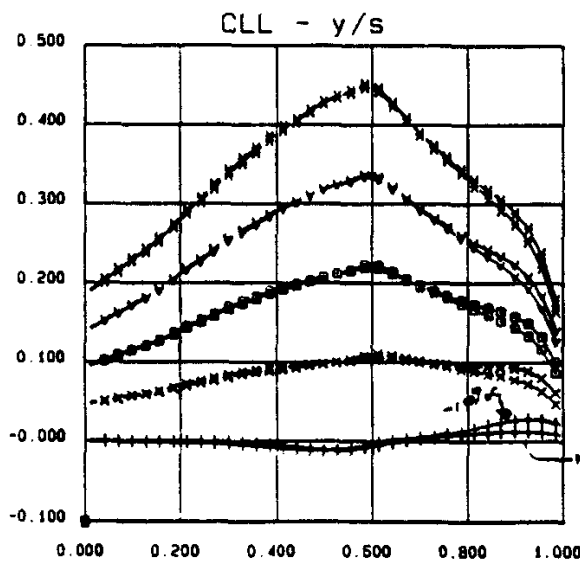
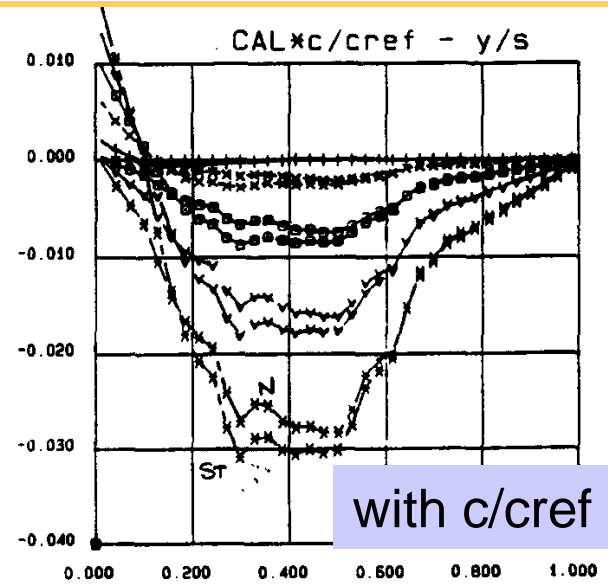
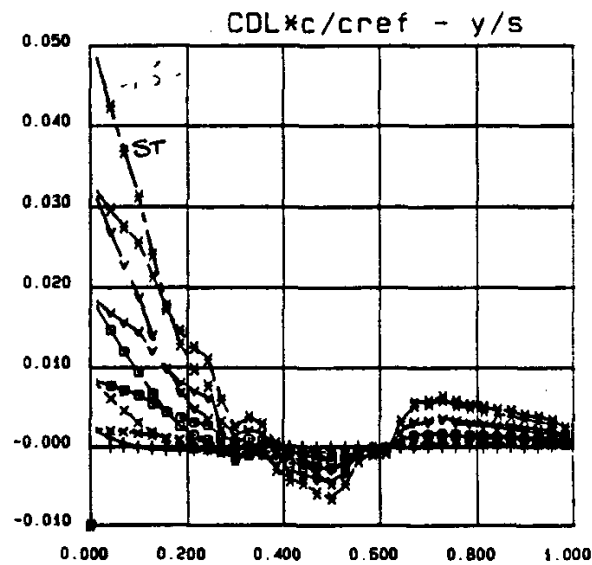
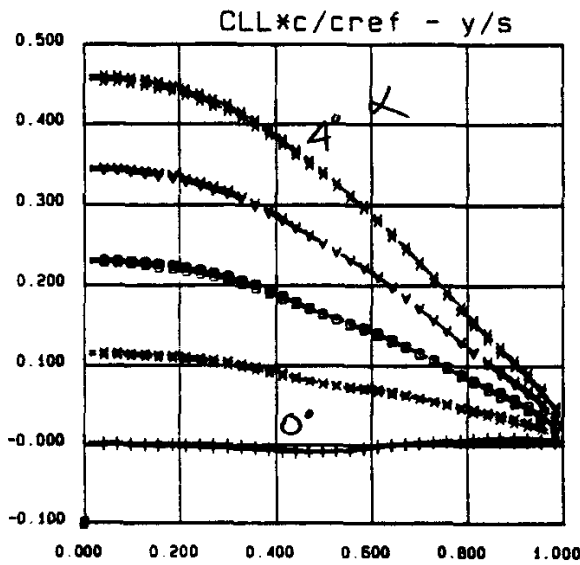
FSW -F1

PLANFORM F1, DESIGNED CAMBER, SPANWISE LOADINGS WITHOUT c/c_{av} FACTOR, STATIC MARGIN VARIES, 10% c_{av} Stable, Neutral & 10% c_{av} Unstable, Mach 0.8

FSW -F1

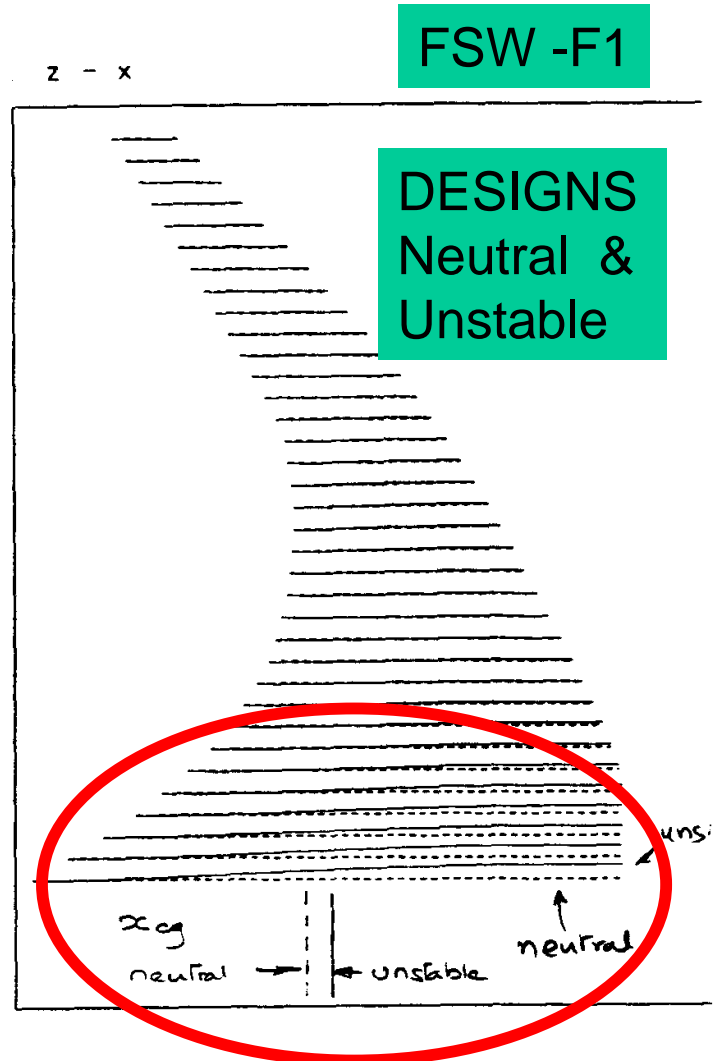
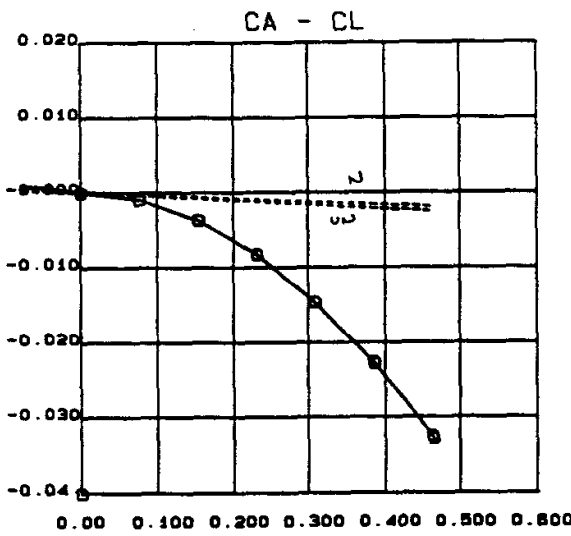
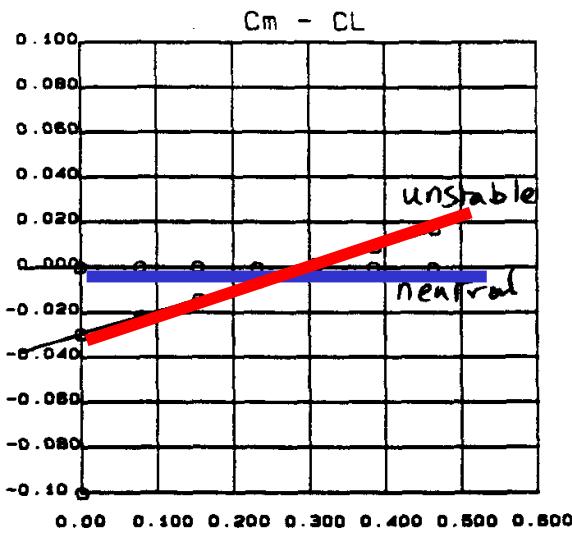
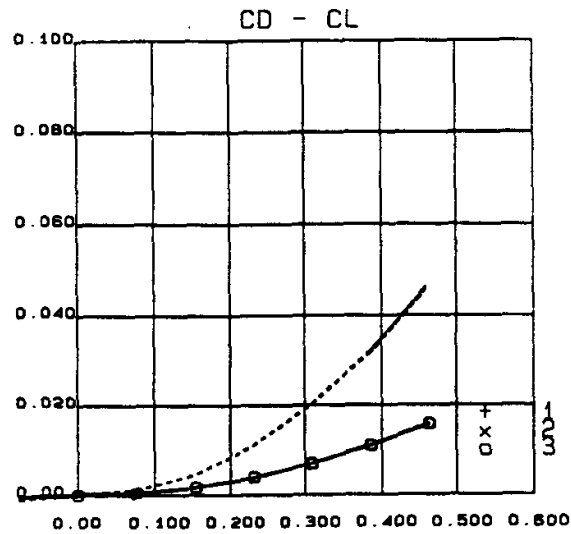
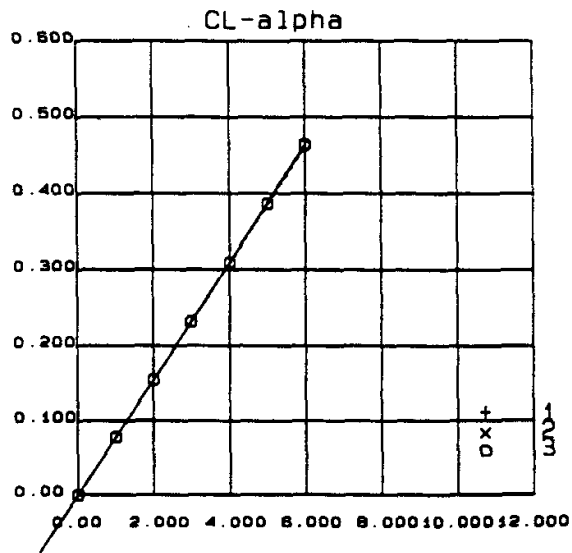
**DESIGNS
Neutral &
Stable**

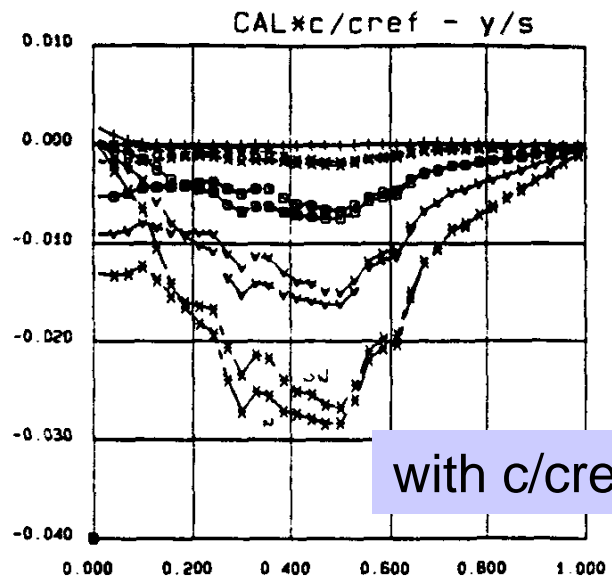
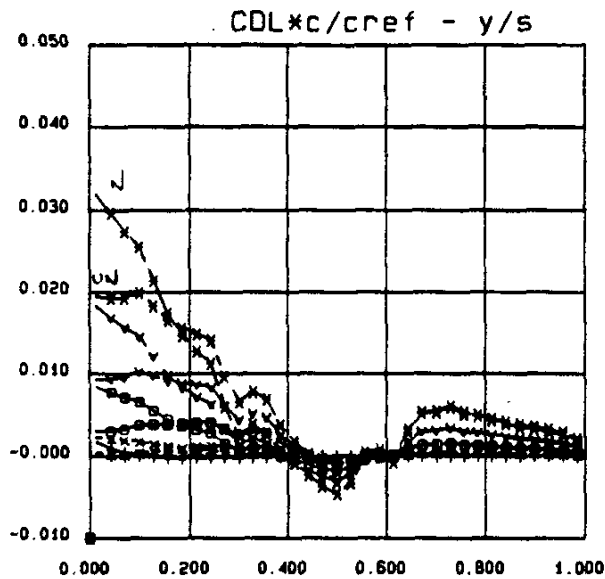
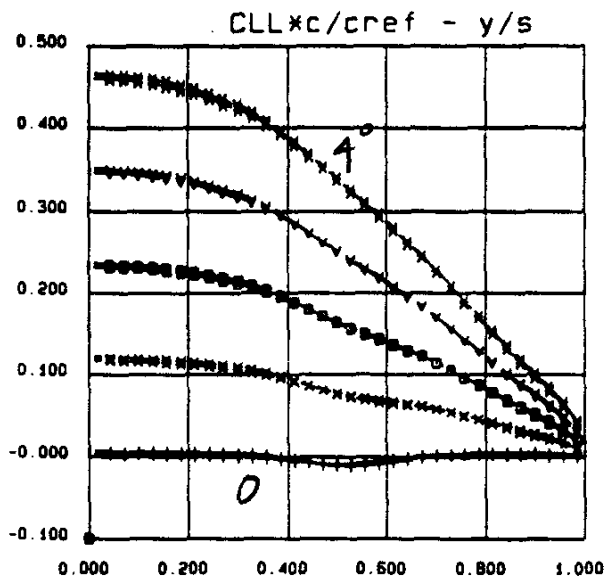




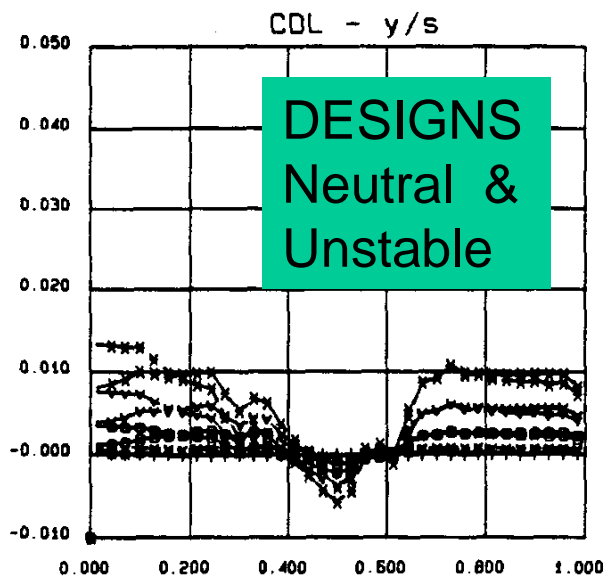
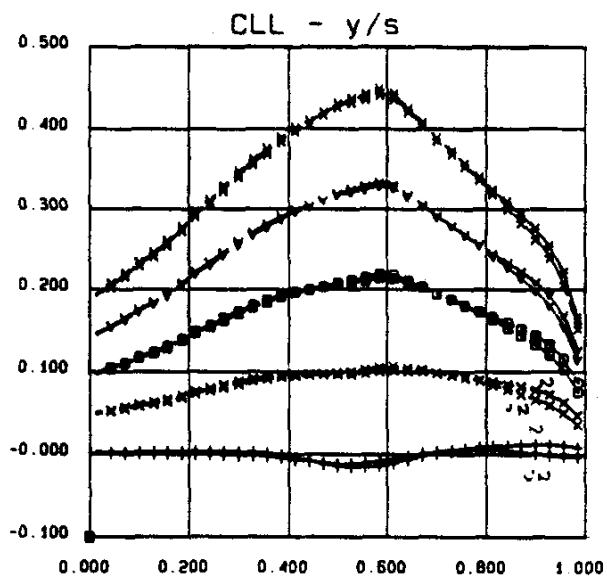
FSW -F1

PLANFORM F1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10% c_{av} Stable, Neutral, Mach 0.8

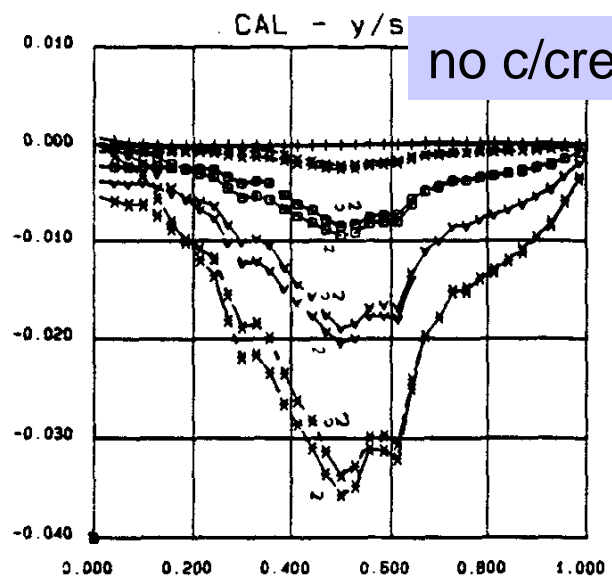




with c/c_ref



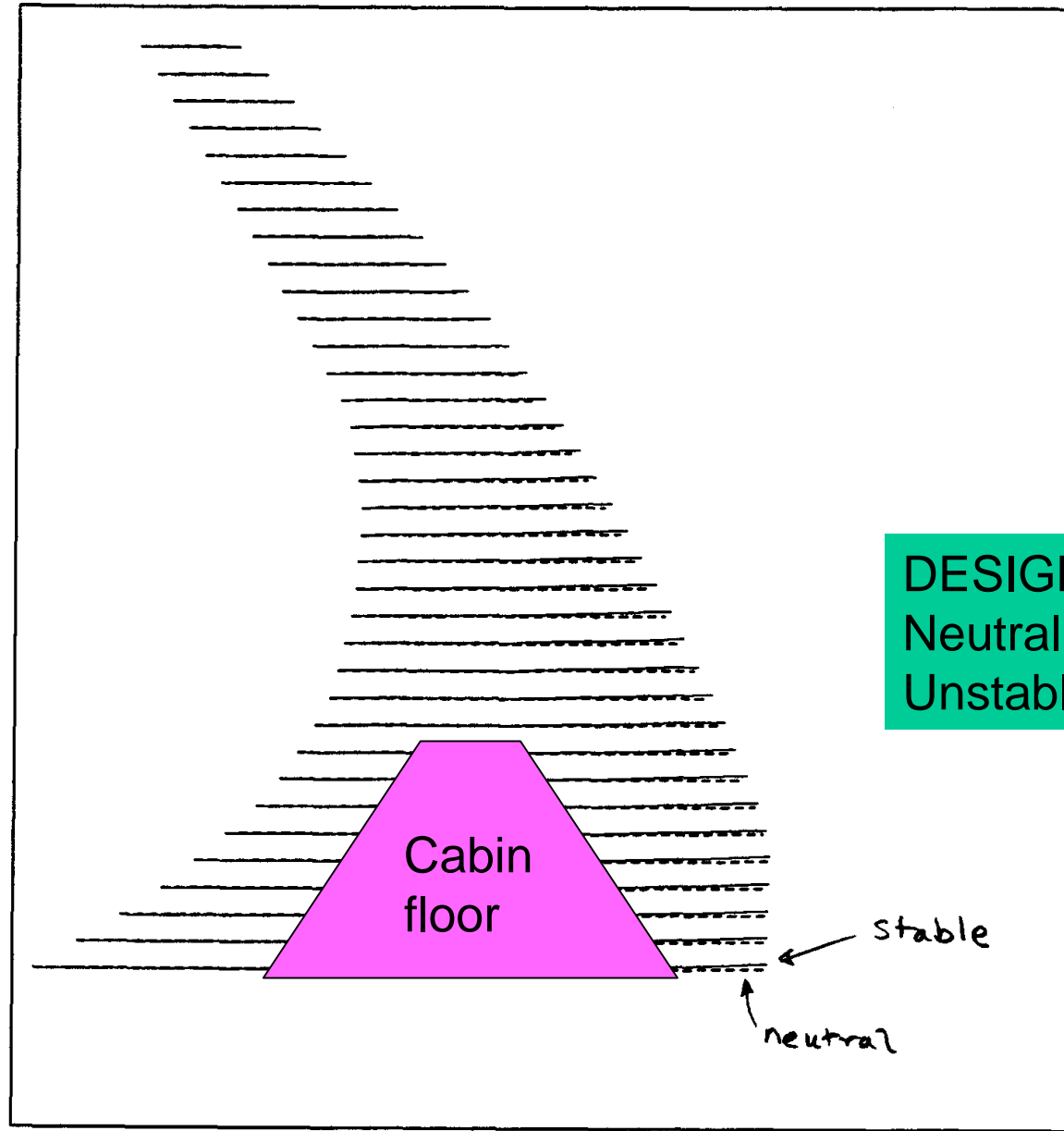
DESIGNS
Neutral &
Unstable



no c/c_ref

FSW -F1

PLANFORM F1, COMPARING FORCES, DESIGNED CAMBER, SPANWISE LOADINGS, STATIC MARGIN VARIES, 10% c_{av} Unstable, Neutral, Mach 0.8



DESIGNS
Neutral &
Unstable



Cabin
floor

stable
neutral

FSW -F1

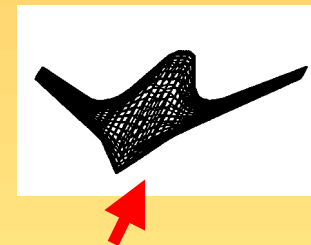
COMPARING DESIGNED CAMBER, STATIC MARGIN VARIES, 0%
Neutral & 10% c_{av} Unstable, Mach 0.8

Design Inferences

- Stable Static margin leads to TE down (higher local Incidence) camber.
- Camber & Twist can be controlled over regions

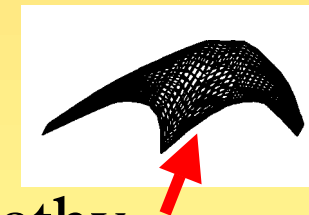
Aft- Swept Wings, Usual

- Outer Wings are more heavily loaded
 - which have to be off-loaded for trim
 - leading to aero centre shifts off-design.



Forward- Swept Wings, A Contender

- Outer Wing are lightly loaded, more in sympathy with planform sweep & chord as well as root BM
- Capitalise on FSW laminar flow
- With Aero-elastic tailoring, structural divergence should be less of a problem on wings of 9% t/c, X-29 was 4% thick.

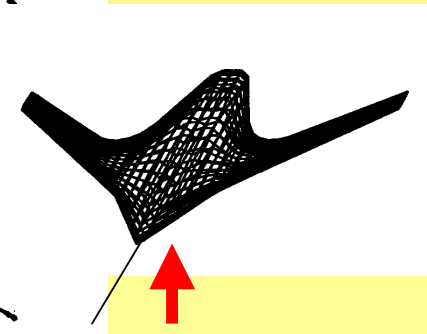
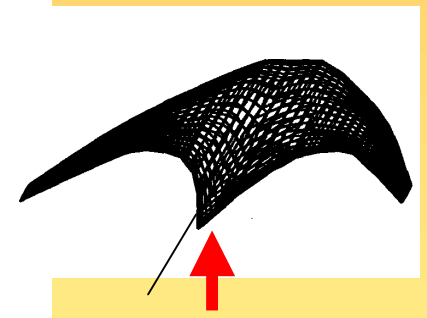
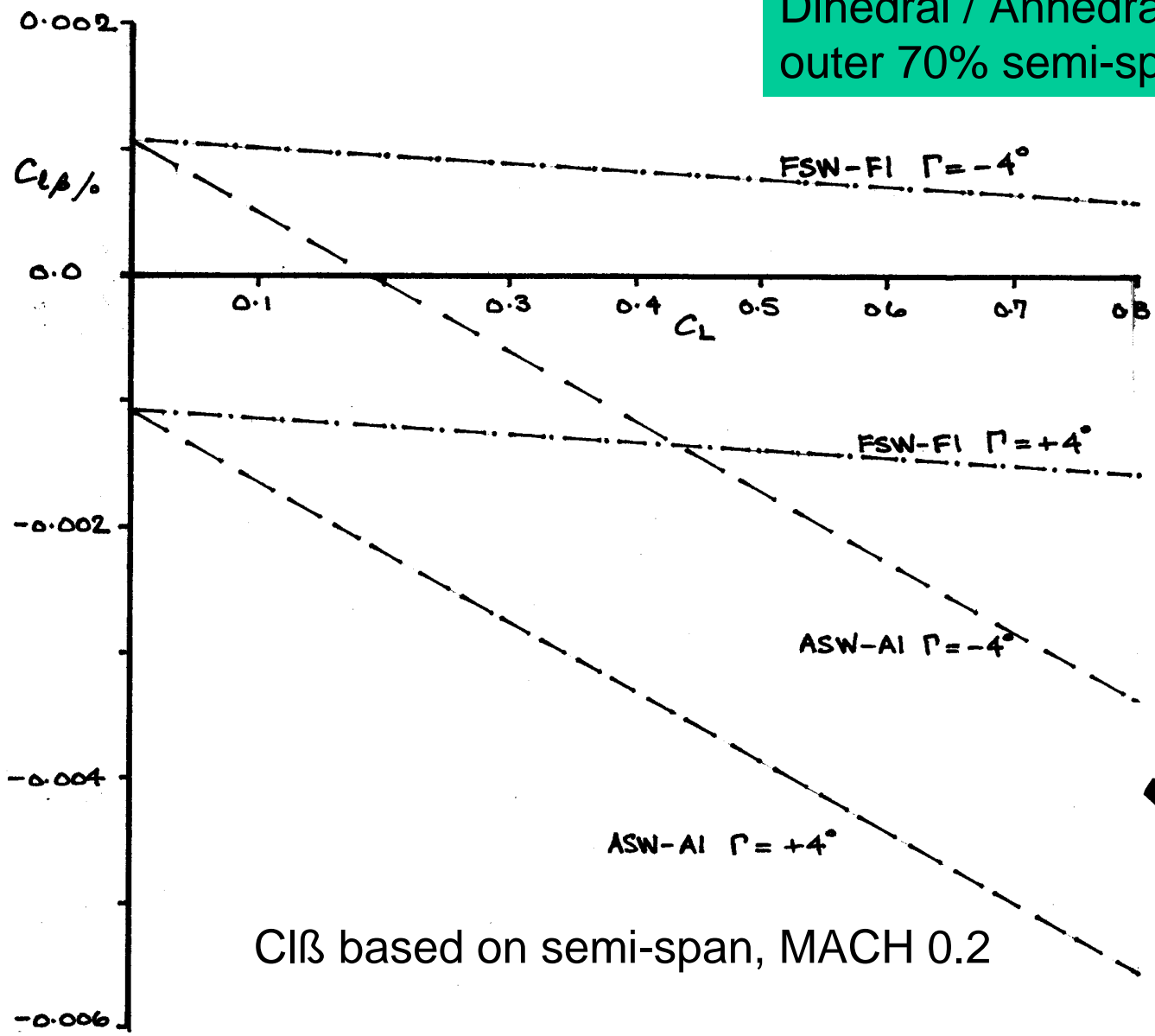


Transports, Directional, Lateral

- Critical - One Engine-Off during take-off or at low-speeds (30 kt cross-wind). Large Aircraft, 80m span
- Ability to hold a 10 deg heading at 75% control power
- Vertical fins exist, low moment arms.
- Can't have Anhedral
- Balancing by Split Ailerons produces drag
 - Low L/D, Climb Gradient affected
- Rudders+Split ailerons
- Initially, side-force dominates before yawing effects come in (high inertia in yaw)
 - No more than 30 m “drift” permitted on runways
- Continual Research needed.

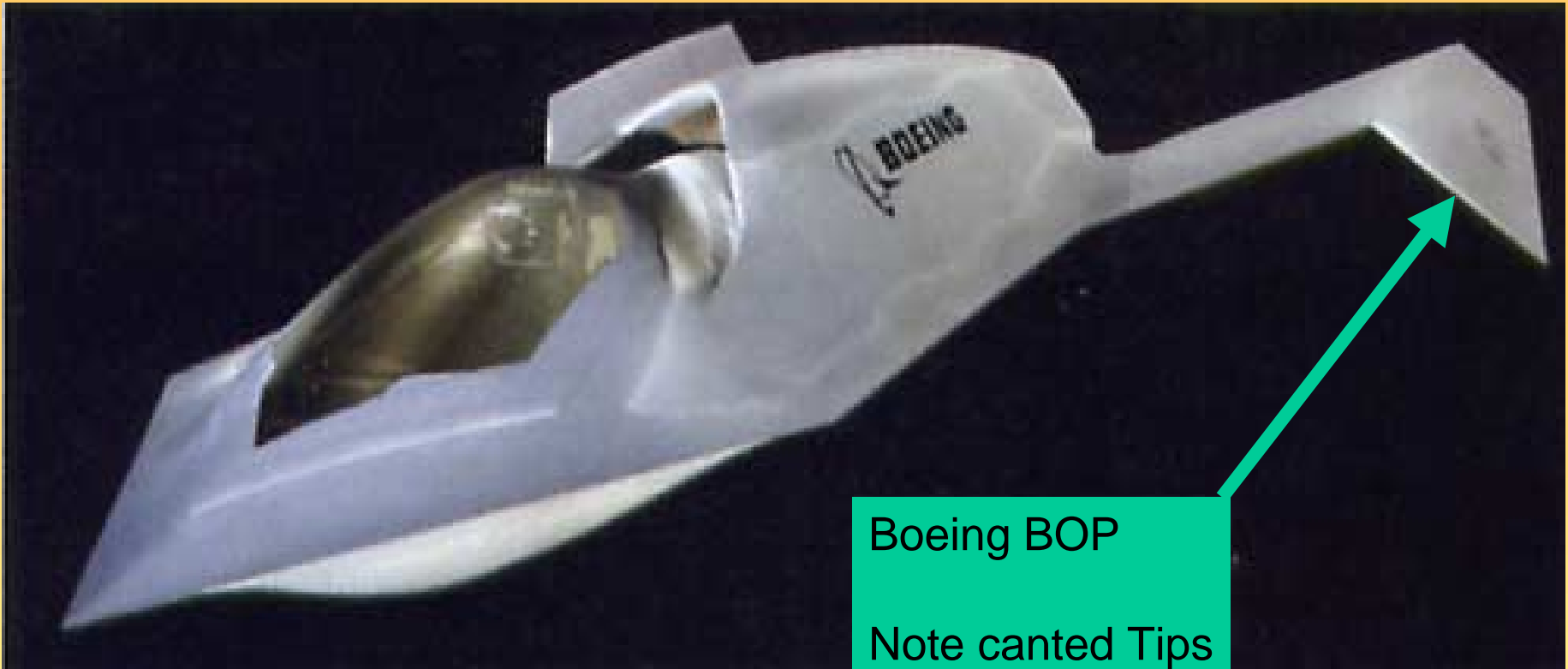
Lateral Characteristics

Dihedral / Anhedral introduced over outer 70% semi-span, PRELIMINARY

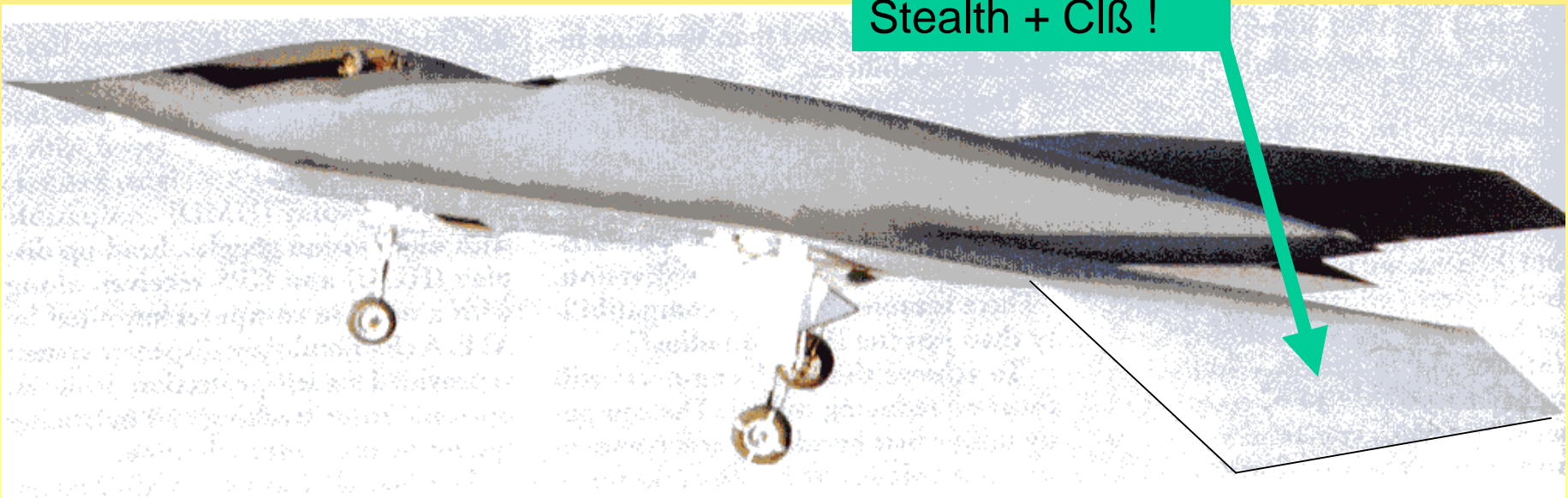


Military Lateral, Directional

- B-2 (No Vertical fins) appears Directionally unstable with Active Control system and sophisticated side-slip measurement
- Adequate Thrust available on Military Aircraft
- Thrust can be deflected / vectored !
- Split Ailerons / Drag rudders for Yaw moment
- Cl_{β} at low speeds, Dihedral/Anhedral Effect



Boeing BOP
Note canted Tips
Stealth + CIB !



Future Work

- More Parametric Studies including FSW
- Combining with Euler for detailed Transonics
- Low-Speed pitch trim using LEF / TEF
- Control Requirements, small moment arms
- Roll & Yaw Coupling, Fins, Dutch Roll
- Off-design effects
- Intakes / Propulsion

Concluding Remarks

- Revival of Interest in Flying Wings for Military & Civil, different set of Constraints summarised, e.g. Low CL
- Appreciation of Solvers, Linear Theory, Euler
 - Understanding & Quick turn-around needed
- Strategy: Appropriate Solvers with Stability Constraints
- Aft- & Forward- swept planforms Designed & studied with lifting surf. theory (Mach & Re. & Attained thrust) ts
- Capitalise on FSW laminar flow
- With Aero-elastic tailoring, structural divergence should be less of a problem 9% t/c wings (X-29 was 4% t/c).
- Preliminary work on Laterals, FSW permits Dihedral

***** Thank You for Listening *****

**Barely touched the surface of this
vast subject, plenty more to do!**

**There are Experts in the Audience
Shall we try Comments and
Discussion**

