Geometric and Computer Analysis of the F-35A Lightning II

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http://www.jsf.mil/images/f35/f35_variant_ctol.jpg

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http://www.jsf.mil/images/gallery/sdd/f35_test/a/sdd_f35testa_054.jpg

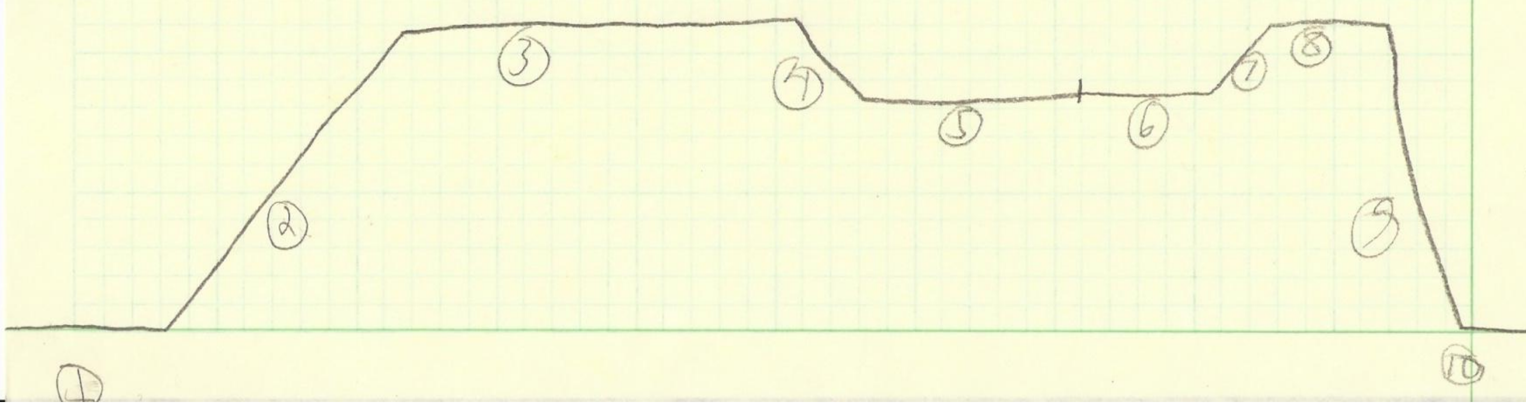
NOTE: All units are in basic English unless otherwise noted.

1. Mission Profile

Generic Mission Profile

1. Takeoff
2. Ascent to cruise
3. cruise to target
4. Descent to attack altitude
5. Bombing run
6. Supersonic out of target area for safety
7. Ascent to cruise
8. cruise back to base
9. Final Descent
10. Landing

Most potential for being attacked in dog fight or S.A.M's (steps 4–7)

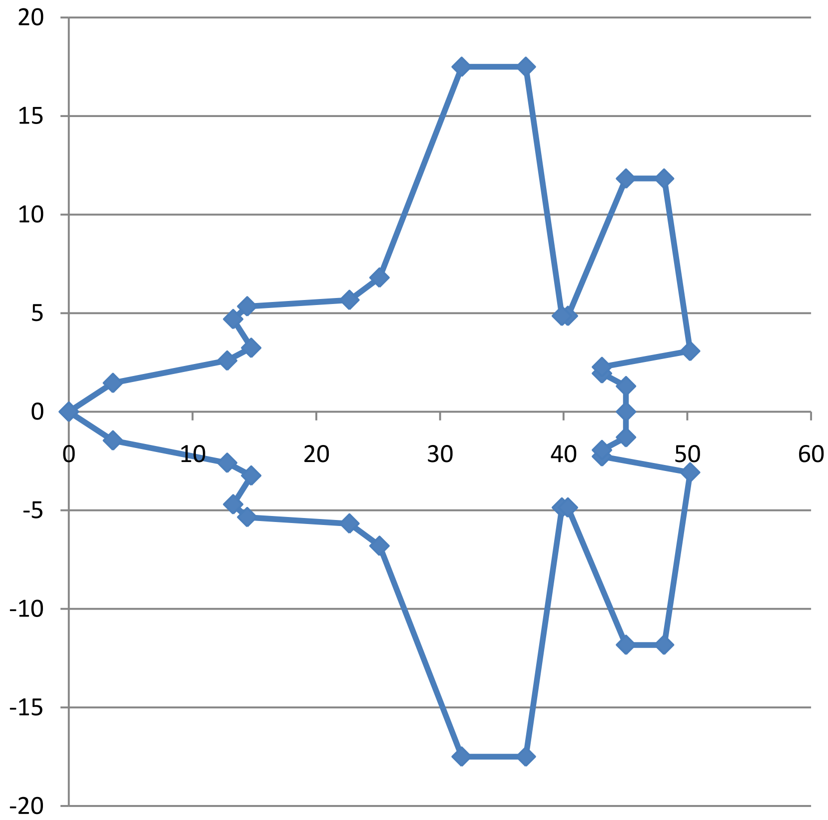


2. Basic Published Geometry

EXTERNAL DIMENSIONS

Dimension	Value
Span	35.01
Overall Length	51.41
Overall Height	14.99
Tail Span	23.92
Wheel Track	14.24
Wheel Base	19.75
Gross Wing Area	460.05
Flap Length	1.35
Aspect Ratio	2.663

3. Planform Plotting and Measurements



http://upload.wikimedia.org/wikipedia/commons/1/19/F-35A_Top.jpg

4. Geometry From Planform Plotting

Dimension	Value
Total Horizontal Tail Area	128.73
Total Vertical Tail Area	85.61
Vertical Tail Taper Ratio	.590
Wing Taper Ratio (λ)	.243
C_{root}	21.19
C_{tip}	5.15
L.E. Sweep	34.13^o
C/4 Sweep	24.16^o
T.E. Sweep	-13.01^o

5. Basic Published Weights, Loadings, and Performance

Parameter	Value
Empty Weight	29035
Max Weapon Load	20000
Max Internal Fuel Weight	18479
Weight Normal TO	53683
Weight Max TO	59525
Wing Loading Max	130.43
Thrust Dry (assume cruise altitude)	28000
Thrust Wet (assume cruise altitude)	43000
T/W Full Fuel	.87
T/W Half Fuel	1.07
Max Speed	Mach 1.6
Cruise Speed	Mach 0.73
Combat Radius (Miles)	679
G-Limit	+9

6. Notable Features

- Air Force variant, C.T.O.L, non-supercruise, midair refueling
- Power-by-wire flight control, hydraulic actuators
- Maintenance: 30%-40% increase compared to current fighter-bombers
- Armament: internally mounted 25mm cannon, various ordnance (external cannon for other variants), capable of externally mounted weapons / fuel tanks as well
- Basically the X-35 enlarged version

http://attach.high-g.net/attachments/gau22_129.png

7. Structural Materials

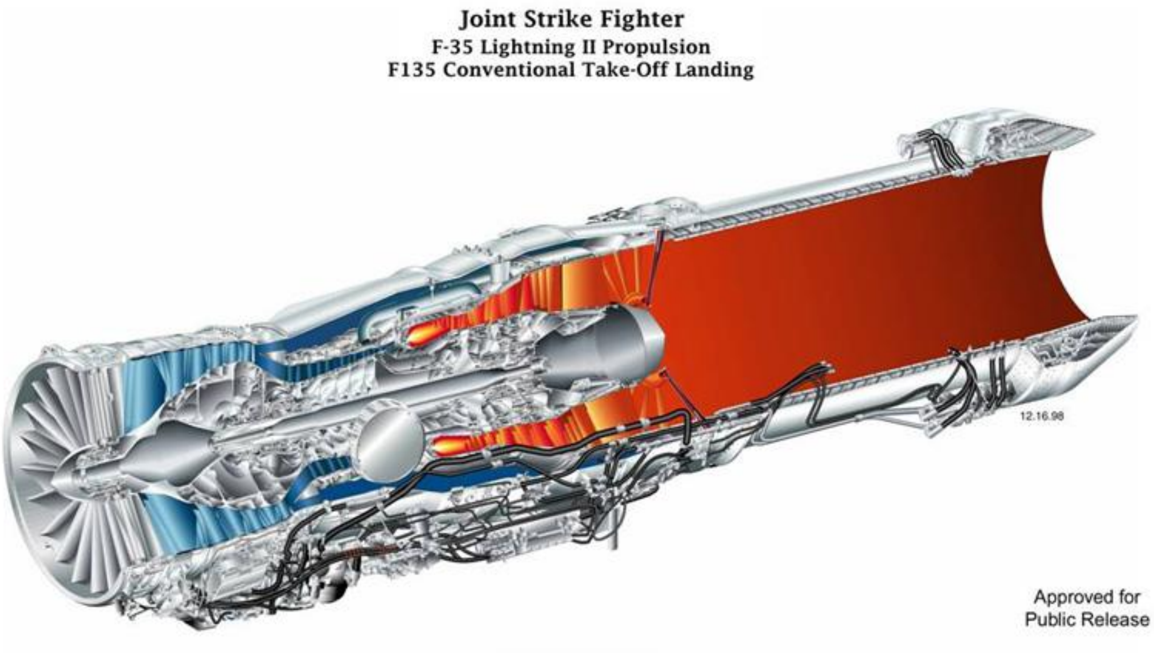
- Bismaleimide (BMI)
- Composite Epoxy Material
- Gap filler, less galvanic corrosion to skin than F-22, fewer gaps in skin
- Structural fibremat

8. Stealth Features

- parallel surfaces
- minimal amount of joints (integrated airframe)
- axisymmetric nozzle
- structural fibremat

9. Engine Variant

- Pratt & Whitney F-135 Turbofan (C.T.O.L Air Force Variant)
- No thrust vectoring or supercruise
- 3-Stage Fan
- 6-Stage Compressor
- Annular Combustor
- 1-Stage HPT
- 2-Stage LPT
- Dry Thrust: 28000 lb (altitude not specified)
- Wet Thrust: 43000 lb (altitude not specified)



http://www.aviationnews.eu/blog/wp-content/uploads/2010/06/f135-ctol-cutaway-low.jpg

10. C.G. Location Calculation

- When calculating the C.G. location, a tip-back angle of 15° from the rear landing gear was assumed. Simple trigonometry was then used to find the location.
- From the image below and the use of a protractor, the tail scrape angle was found to be about 15.5°.
- Vertical location assumed to be midline of aircraft (no other data available)

http://www.airforce-technology.com/projects/jsf/images/img7.jpg

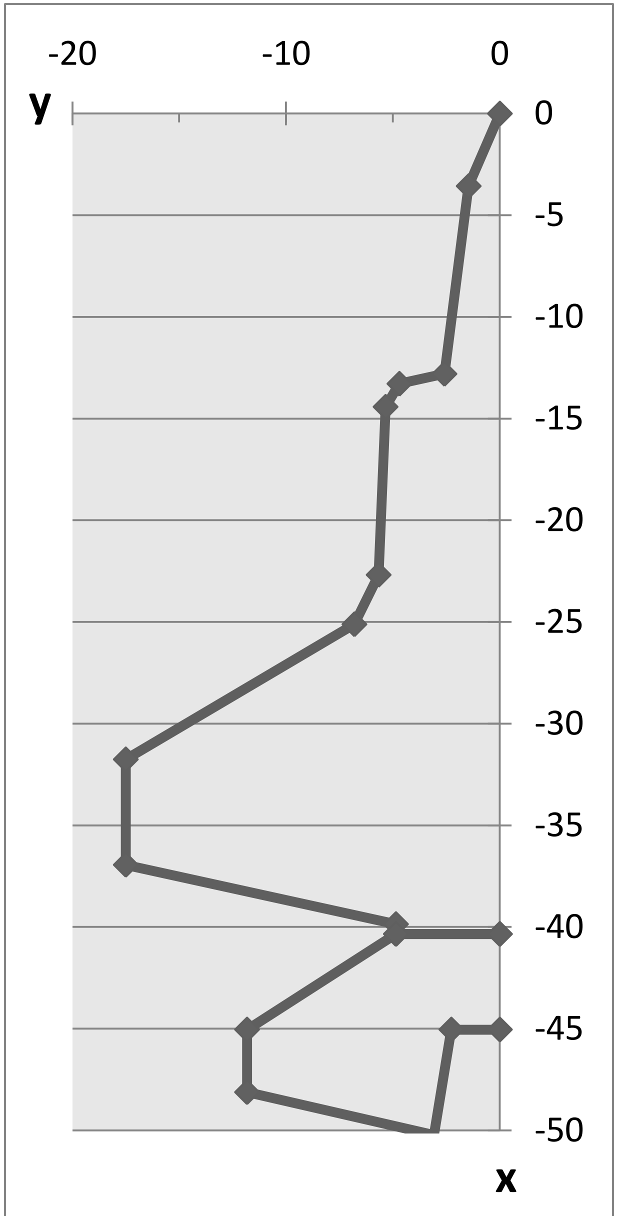
Mean Aerodynamic Chord

- M.A.C=14.798 ft λ=.243

$$M.A.C = \frac{2}{S}\int_{0}^{b/2} c^2 dy = c_R\left(\frac{2}{3}\right)(1+\lambda+\lambda^2)+(1+\lambda)$$

- Wing begins at 25.116 ft from nose
- C.G. Location in % M.A.C shown below

$$\frac{30.26-25.116}{14.798} = C.G.\, in\, \%M.A.C = 34.76\%$$



11. Stability Analysis with VLMpc

- Using manual iterations the neutral point was found by finding the x-location where $dC_m/dC_l=0$
- From the neutral point and calculated CG, the static margin can be determined.
- VLM also outputs $C_{L\alpha}$ and $C_{m\alpha}$. Results on next slide.

VLMPc Results

Parameter	Value
$C_{l\alpha}$	3.614 /rad
C_m/C_L	0.116
$C_{m\alpha}$	0.151/rad
Static Margin	-11.6%
X-location NP	28.51 ft
X-location CG	30.26 ft 34.76 %M.A.C

$$C_{M\alpha} = \left(\frac{dC_M}{dC_L}\right)\left(\frac{dC_L}{d_\alpha}\right)$$

$$Static\ margin\ = -\frac{C_M}{C_L}$$

$$Static\ margin = \frac{h_{np} - h_{cg}}{c_{mac}}$$

12. Aerodynamic Analysis

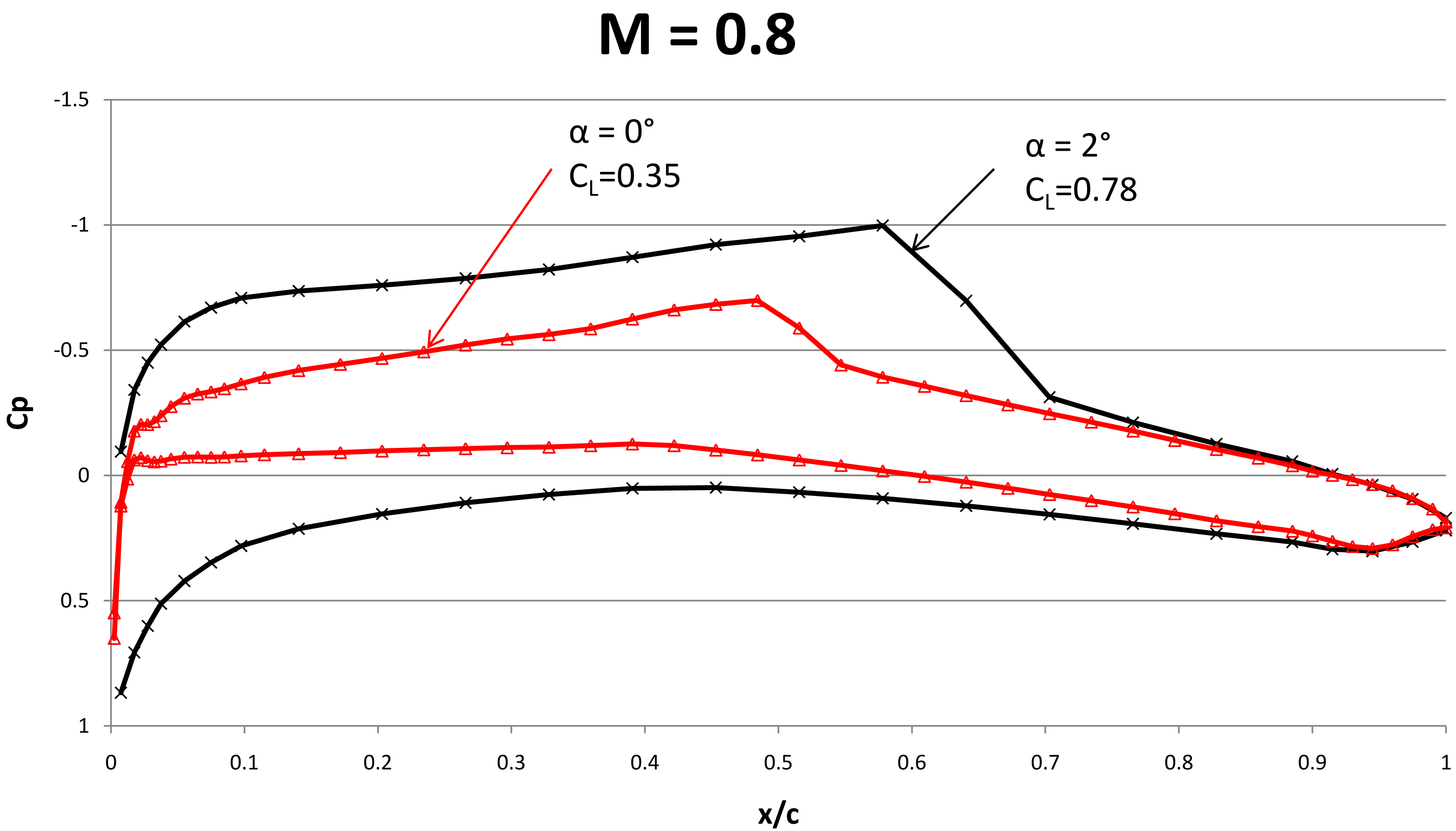
1. Airfoil Analysis]
2. Drag Divergence
3. LIDRAG Results
4. Cruise Drag Breakdown
5. LamDes Trim Performance Results
6. High-Lift Devices Discussion

Airfoil Analysis

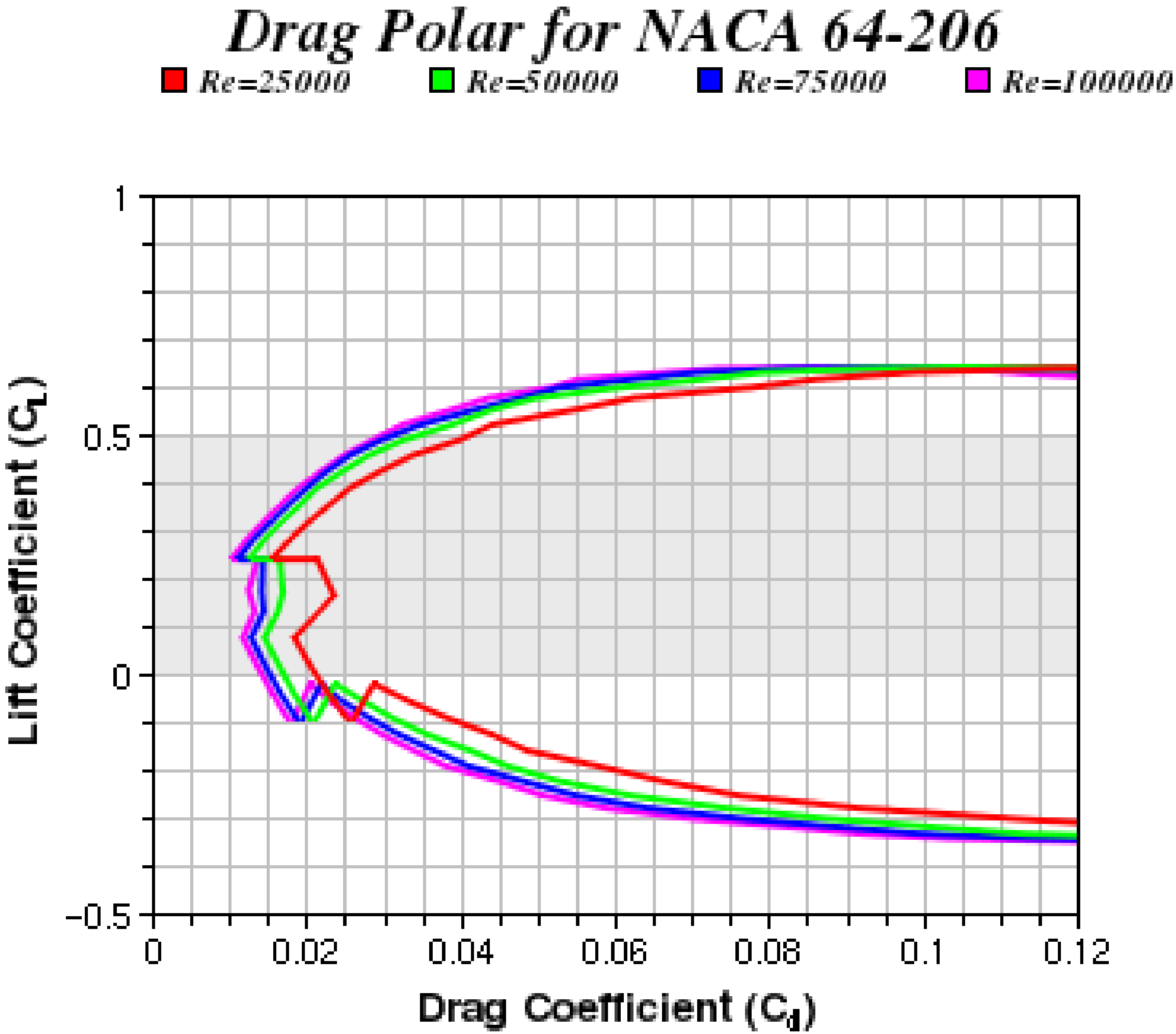
- No readily available data on airfoil. Assumed airfoil based off of aircraft designed for similar missions

	F-15 Eagle	F-16 Falcon	F/A-18 Hornet	F-20 Tigershark	F-22 Raptor	F-35A Lightning II
Root	64A(.055)5.9	64A204	65A-005 mod	65A004.8	64A?05.92	64A-206
Tip	64A203	64A204	65A-003.5 mod	64A004.8	64A?04.29	64A-206

NACA 64A-206 Pressure Distribution (TSFOIL2)

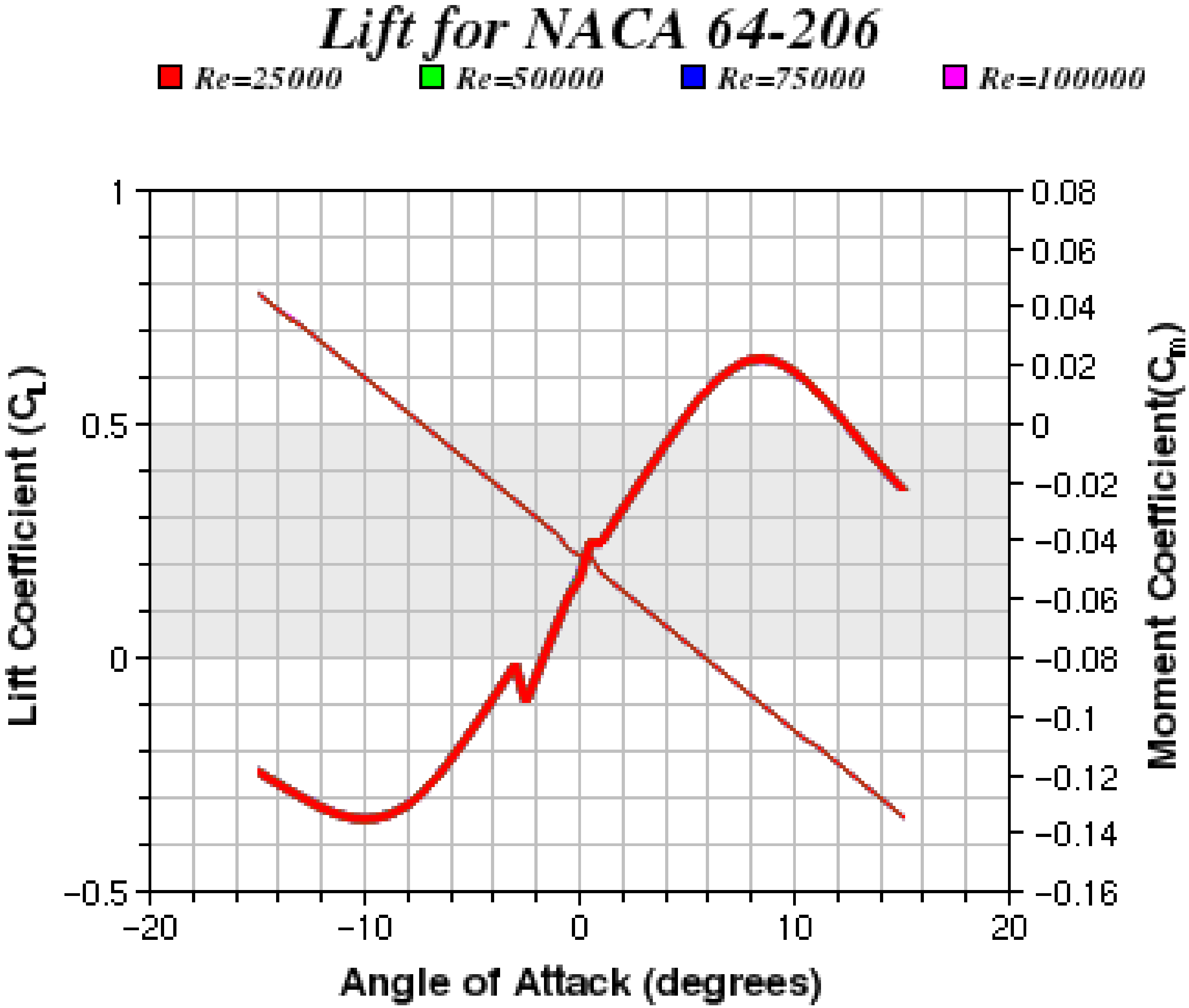


NACA 64A-206 Drag Polar



http://www.worldofkrauss.com/foils/draw_polar/1679

NACA 64A-206 C_l and C_m vs. α



http://www.worldofkrauss.com/foils/draw_lift/1679

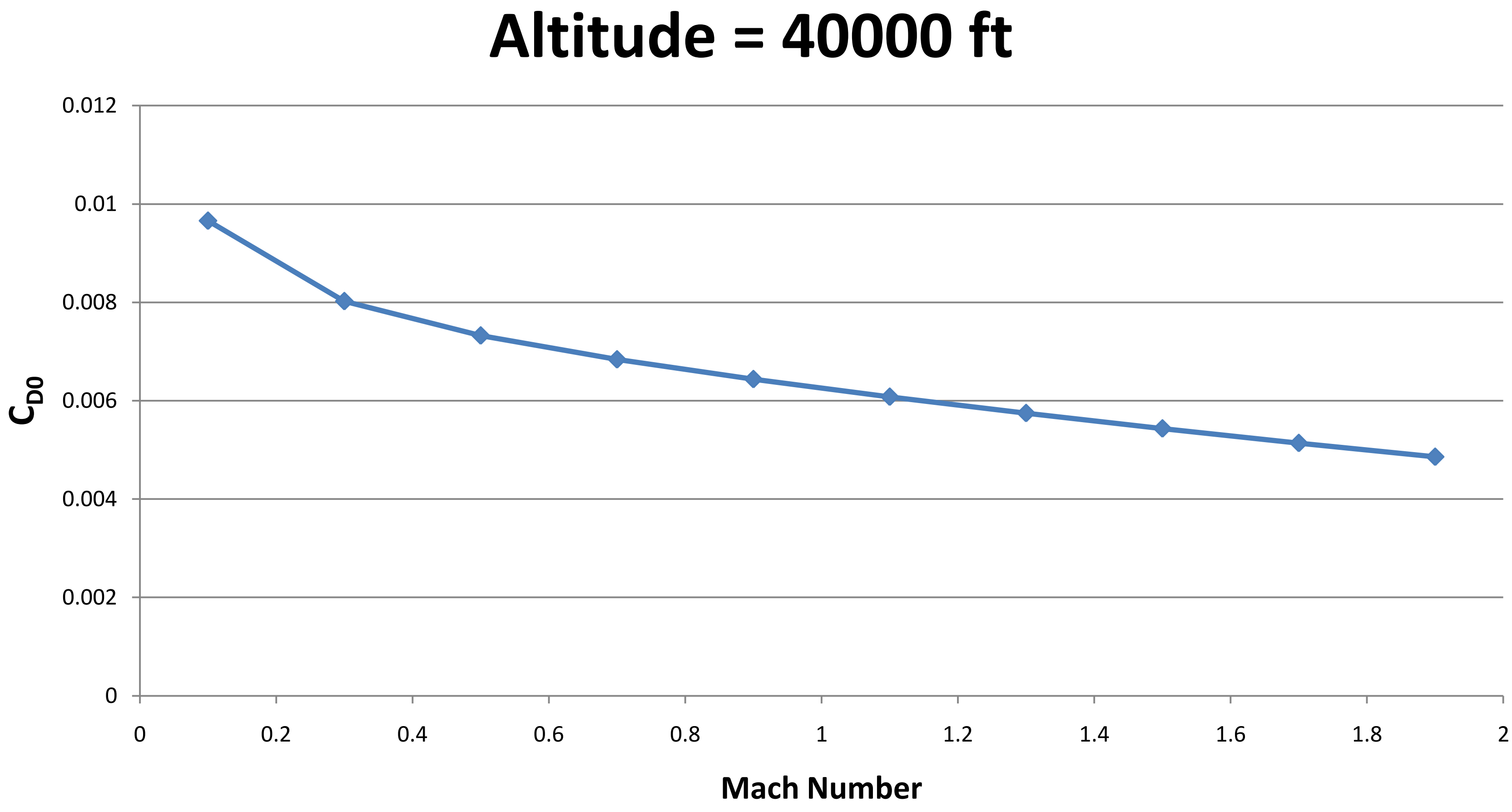
Drag Divergence – Hand Calculated

Parameter	Value
k_A	.87-.95=.91
$\Lambda_{quarter\text{-}chord}$	24.16^o
t/c (Airfoil Thickness)	.06
C_l (From VLMPc, average along span)	.580
M_{DD}	.849
$M_{critical}$	.741
M_{cruise} (Decision Based)	.73

$$M_{DD} = \frac{k_A}{\cos(\Lambda)} - \frac{t/c}{\cos^2(\Lambda)} - \frac{C_l}{\tan^3(\Lambda)}$$

$$M_{critical} = M_{DD} - \left(\frac{0.1}{80}\right)^{1/3}$$

Parasite Drag (FRICTION code)



LIDRAG RESULTS

Parameter	Value
Cruise C_L - LIDRAG Result	.736
e - LIDRAG Result	0.85761

$$C_L = \frac{2W}{\rho V^2 S}$$

$$C_{L(L/D)max} = \sqrt{\pi A R e C_{D0}}$$

Drag Breakdown at Cruise

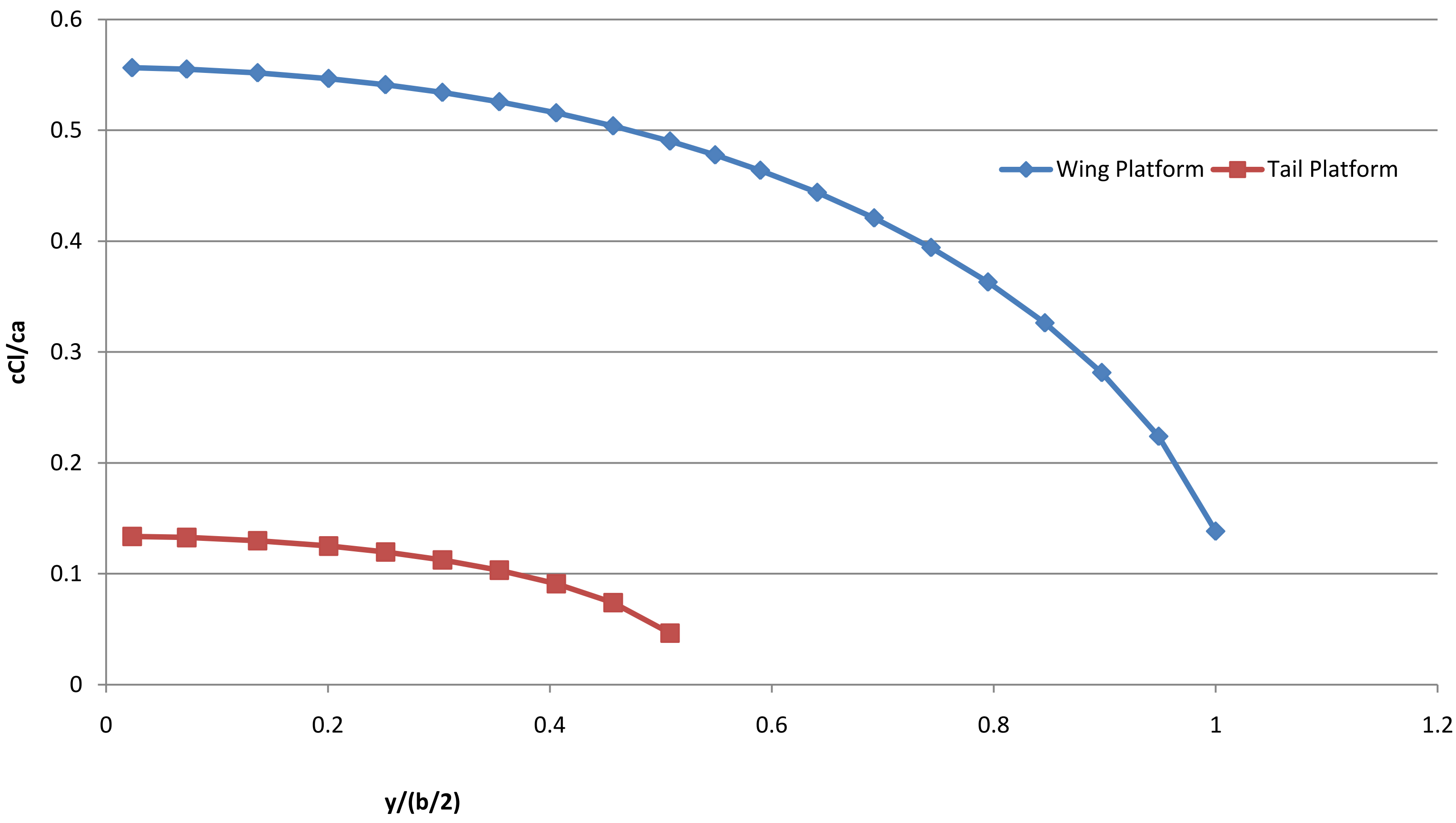
Parameter	Value
C_{D0} FRICTION Result	.007
C_{Di} Hand Calculated	.0755
C_D Hand Calculated	.0825
$(L/D)_{max}$ Hand Calculated	16.01

$$C_{Di} = \frac{C_L^2}{\pi ARe}$$

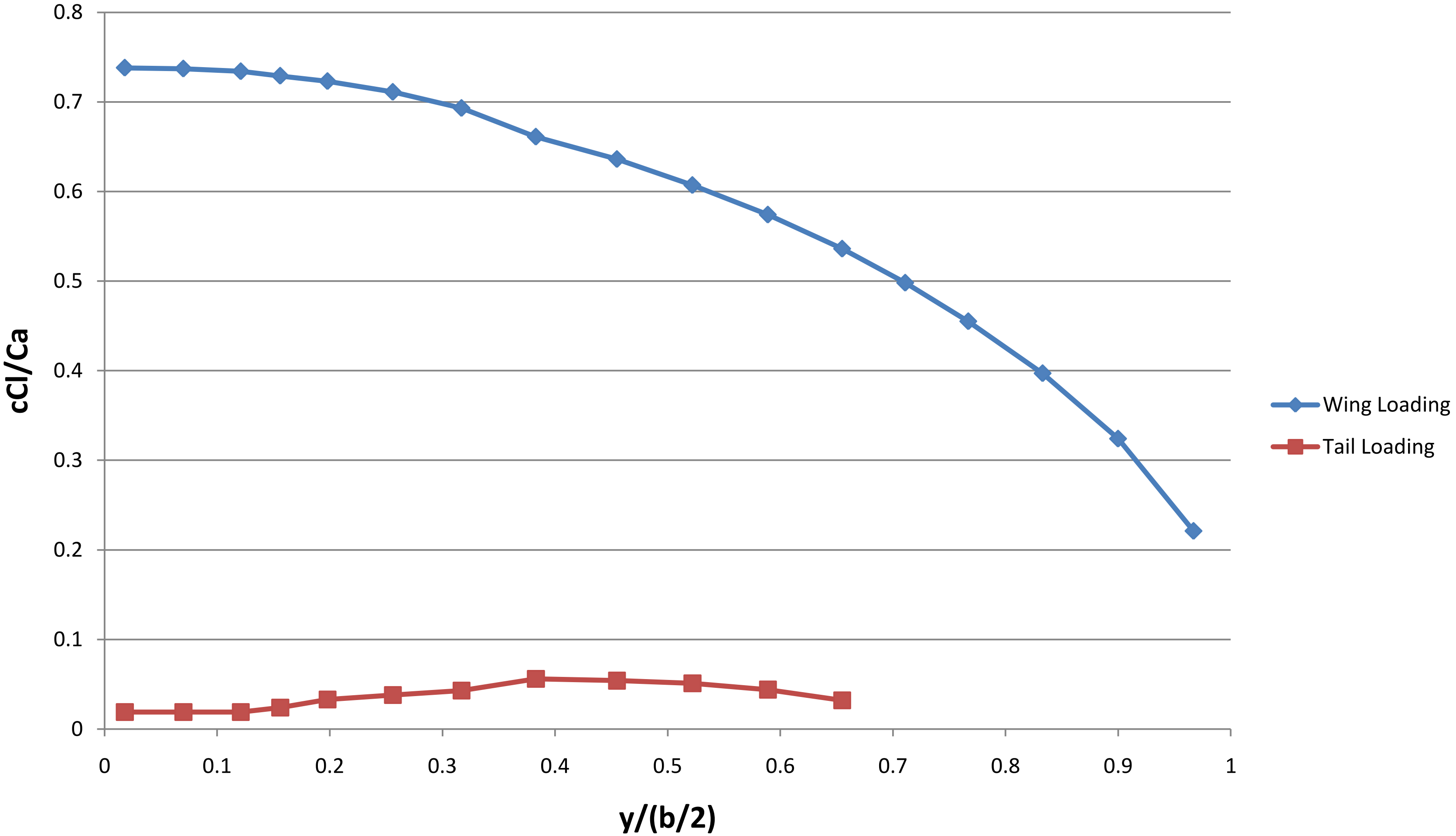
$$C_D = C_{D0} + C_{Di}$$

$$(L/D)_{max} = \frac{1}{2}\sqrt{\frac{\pi ARe}{C_{D0}}}$$

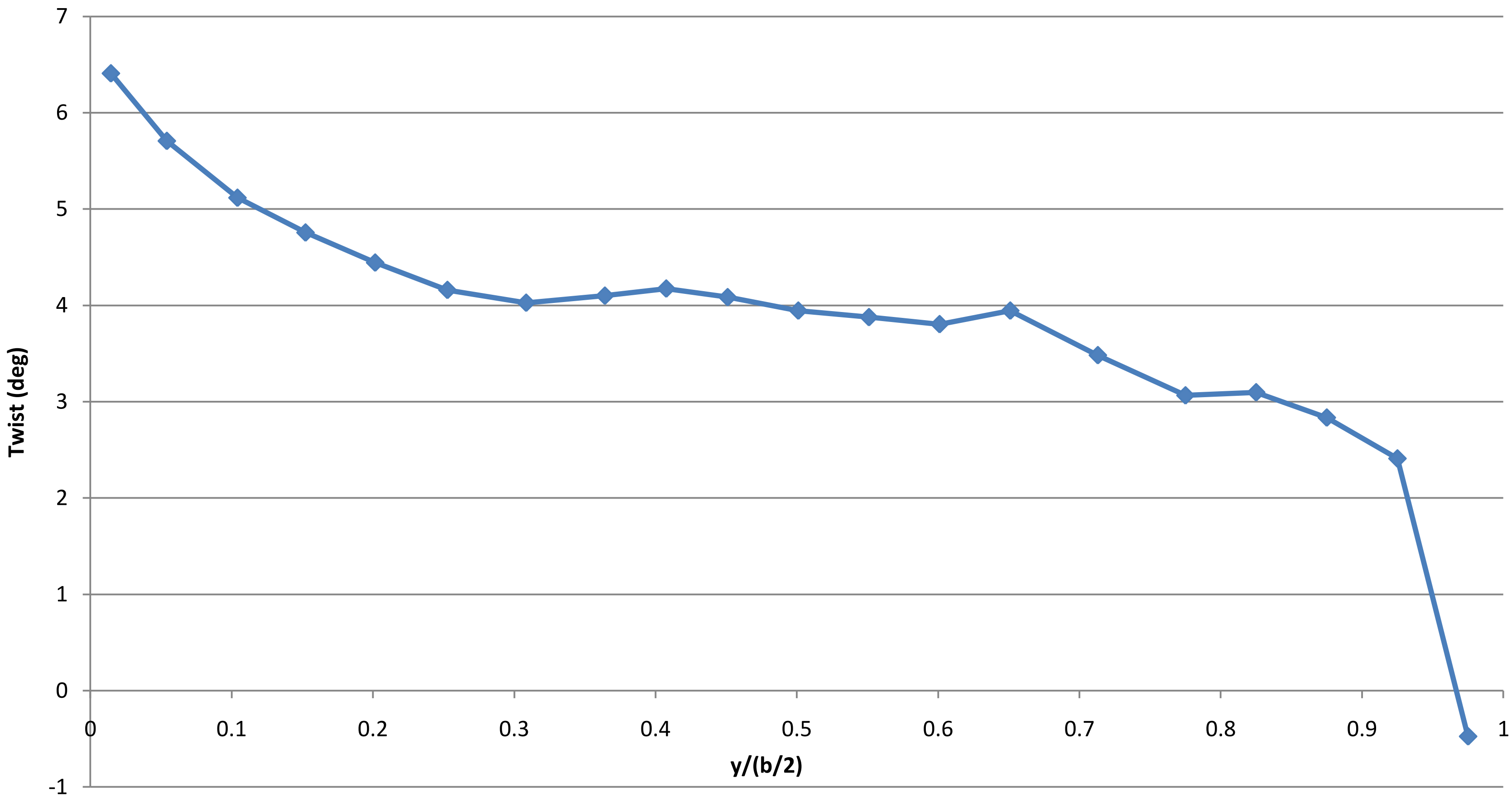
Lamdes Program Output Loading



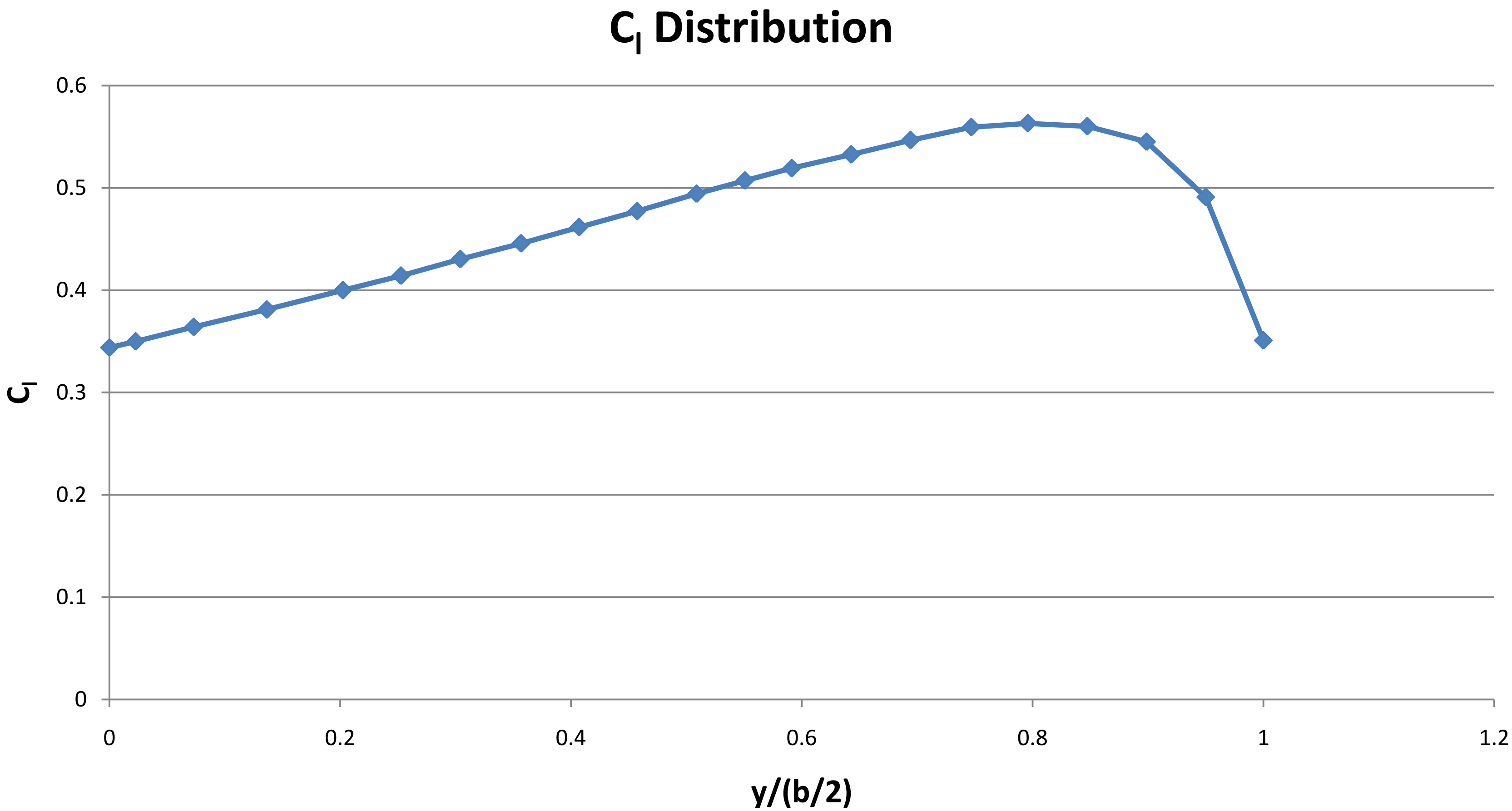
VLM Program Output Loading



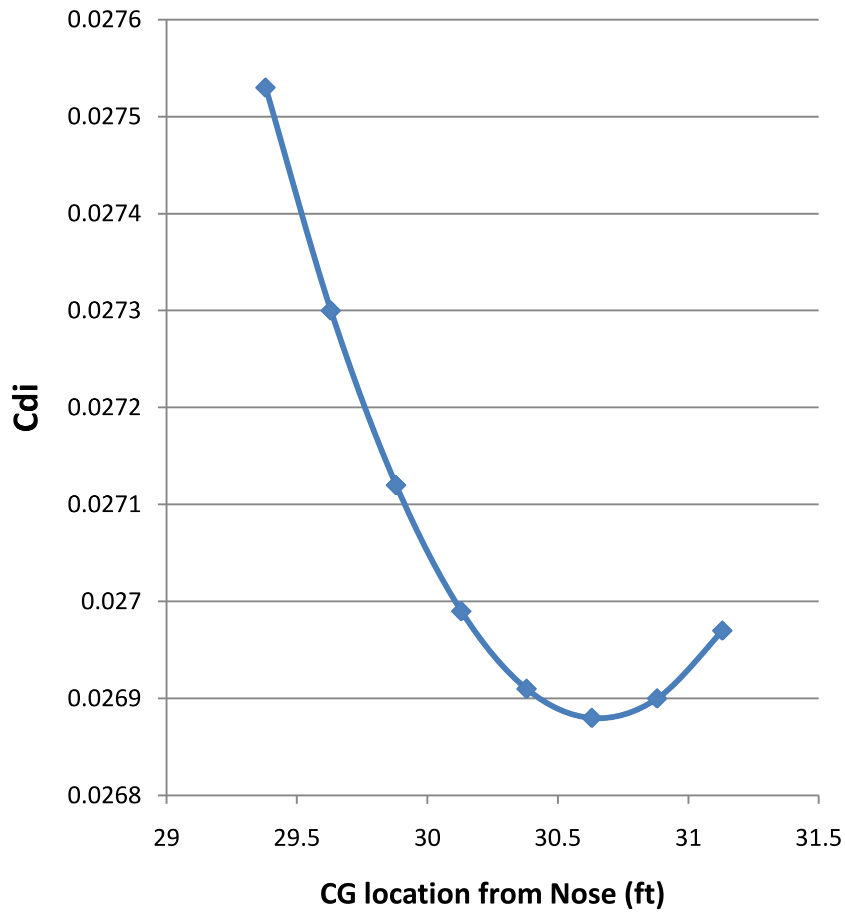
Lamdes Program Output Wing Twist



Cl Spanwise Distribution – Hand Calculated



Lamdes Program Output Trimmed Performance



- Minimum drag occurs at a CG of about 30.6 ft (37.06 %M.A.C)
- This CG would result in a static margin of -13.7%

13. Aircraft Design Discussion

- Wing sweep for drag rise delay (higher cruise speed)
- Angled vertical tails for stealth
- Parallel surfaces for stealth
- Internally mounted cannon for stealth
- Preference of internal bay mounted ordnance for stealth
- In-flight refueling for mission longevity

Aircraft Design Discussion Continued…

- Variants are similar for cheaper manufacturing
- Integrated one-piece airframe for stealth and manufacturing
- Angular shaping all around for stealth
- Basically enlarged version of Lockheed X-35
- Divertless inlet eliminates moving parts for stealth
- Majority of design decisions based on stealth features

References

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6. "Lift-to-drag Ratio." *Wikipedia, the Free Encyclopedia*. Web. 15 Apr. 2011. <http://en.wikipedia.org/wiki/Lift-to-drag_ratio>.

7. Mason, WH., Transonic Aerodynamics of Airfoils and Wings, Configuration Aerodynamics Notes – Chapter 7, 2011