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OEI

AE460 Aircraft Design

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Lecturer

Background

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- Multiple engine aircraft have to be analyzed to understand and be able to mitigate the effects of a one engine inoperative (OEI) scenario
- Takeoff run, with an engine shutting down, will cause yaw that needs to be corrected by the vertical stabilizer(s) and rudder(s)
- When the pilot recognizes the engine out, he/she need to know whether to continue to takeoff or pull back on the throttle and hit the brakes.
- The evaluation is documented by performing a Critical Field Length analysis

Free Body Diagram

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- Figure is a free-body diagram or an engine out and crosswind scenario
- For 460 effort, assume β = 0 (no crosswind) during OEI, and therefore, no Lf (body side lift force).
- If the engine inlet and the nozzle are at different BL locations, i.e. like a typical fighter jet, you will need to separate components of inlet and nozzle drag.

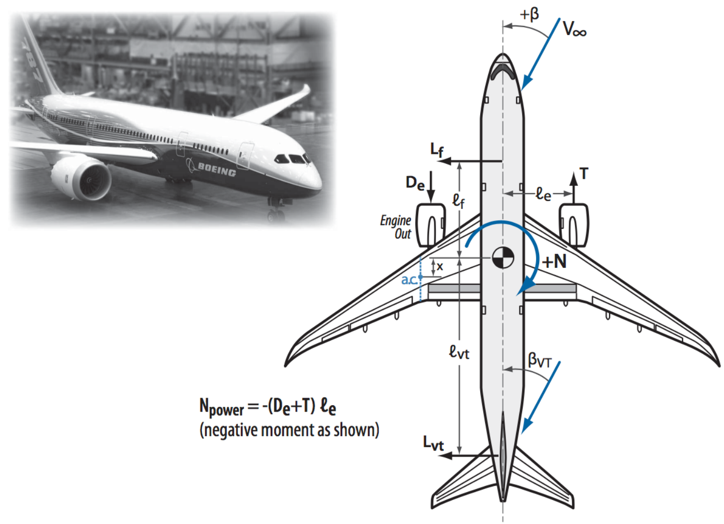

Figure 21.12 Forces on aircraft for directional motion (photograph courtesy of The Boeing Company).

Nicolai

Steps

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- Do the takeoff analysis first, using all engines operating (AEO), just to make sure you meet the takeoff requirements with AEO.
- Perform OEI analysis, using the increased drag and reduced thrust in the stepwise integration of the takeoff analysis (see RCR for detailed graphs to produce)
- Develop the graph as shown in Nicolai, Fig 10.13 for Balanced (or Critical) Field Length.

Example Input

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Flight condition				Propulsion Configuration					Rudder Configuration			
Altitude	0			$V_{noz}/U1$	0.42		RVI 4.5.3.1		c_f/c	0.25		
M	0.17			S_{noz}	20	ft^2	RVI 4.5.3.1		d_{cl}/d_{df}	4	rad^{-1}	RVI Fig 8.14 or N Fig 9.10
Density	0.002377	slugs/ft3		d_{inl}	2	ft	RVI 4.5.3.1		k_{Δ}	0.9		RVI Fig 8.13 or N Fig 9.23
Speed of sound	1116	ft/s		T	23000	lbf	T/O Thrust		S_v	125	ft^2	Vertical Planform
				y_{inl}	4.25	ft	distance to BL0		S_{vr}	120	ft^2	Vertical flapped area
Aircraft Configuration				y_{noz}	1.5	ft	distance to BL0		S_{vr}/S_v	0.96		Variation of N Fig 9.24
S	699	ft^2		l_v	20	ft	CG to Lv					
									n_v	2	number of vertical tails with rudders	
									b	13.2	ft	
									A	2.16	includes 1.55 AR factor for end plate effects	
									e	0.75	est based on F-104 wing	

Example only! Use your aircraft configuration for analysis

Areas similar to N Fig 9.24, but using the vertical tail/rudder vs. wing and flap

Lift and Drag vs. Rudder Deflection Analysis

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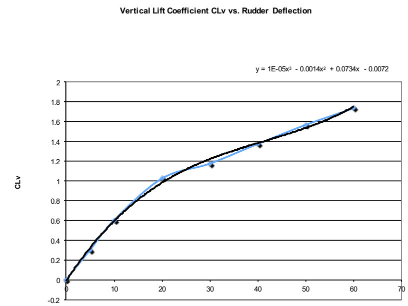
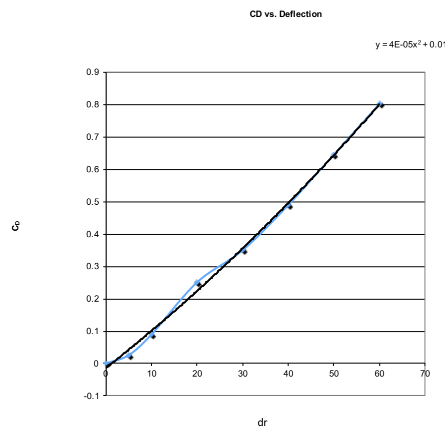
Drag based on vertical stabilizer area, assumed alfa=0 and zero crosswind

Rudder deflection	R VI Fig 8.13 or N Fig 9.9	R VI Eq 8.4 (variation of N Eq 9.2)	R VI Eq 8.29 or N Eq 9.9	N Fig 9.26, drag increment	N Fig 9.27, drag increment	N Eq 9.10	drag due to lift	Drag based on defelection
δr	K'_f	c_{lv}	C_{Lv}	k1	k2	ΔC_{Doflap}	C_{Dv}	C_D
degrees								
0	1	0.00	0.00	1.4	0.000	0	0.00000	0
5	1	0.35	0.30	1.4	0.006	0.00776	0.01787	0.02563
10	1	0.70	0.60	1.4	0.013	0.01761	0.07147	0.08908
20	0.85	1.19	1.03	1.4	0.033	0.04395	0.20655	0.25050
30	0.65	1.36	1.18	1.4	0.058	0.07782	0.27176	0.34958
40	0.57	1.59	1.38	1.4	0.088	0.11760	0.37153	0.48913
50	0.52	1.82	1.57	1.4	0.120	0.16168	0.48313	0.64482
60	0.48	2.01	1.74	1.4	0.155	0.20845	0.59280	0.80125

coefficients from k2 vs. dr graph curve fit equation	
x3	-2.00E-07
x2	4.00E-05
x1	0.0009
x0	0.0003





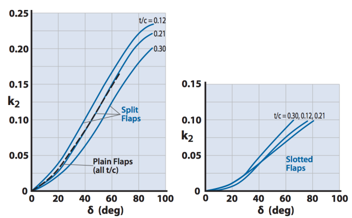


Figure 9.27 Factor k_2 to calculate drag increment due to flaps.

Develop curves based on your configuration

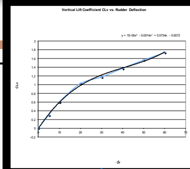
OEI Drag Components

- **Warning!** Be aware that when working with non-dimensional coefficients, i.e. C_L ,C_D or C_M , that you need to keep track of the reference area or reference length you are dealing with. So when someone asks for a coefficient, you always provide the reference area with the coefficent.

				Ref Area S				Ref Area S_v	
Airspeed	Airspeed	Dynamic Pressure	Mach Number	RVI Eq 4.67	RVI Eq 4.67	equiv flat plate area	equiv flat plate area	re-reference to Svt	re-reference to Svt
V	V	q	M	$\Delta C_{Dwmj - inl}$	$\Delta C_{Dwmj - noz}$	f_{inl}	f_{noz}	$\Delta C_{Dwmj - inl}$	$\Delta C_{Dwmj - noz}$
knots	ft/sec	psf				ft^2	ft^2		
60	101.3	12.19	0.09	0.00045	0.01392	0.31	9.73	0.002512	0.0778
70	118.1	16.59	0.11	0.00045	0.01391	0.31	9.73	0.002512	0.0778
80	135.0	21.67	0.12	0.00045	0.01391	0.31	9.72	0.002512	0.0778
90	151.9	27.43	0.14	0.00045	0.01390	0.31	9.72	0.002512	0.0777
100	168.8	33.86	0.15	0.00045	0.01389	0.31	9.71	0.002512	0.0777
110	185.7	40.97	0.17	0.00045	0.01388	0.31	9.70	0.002512	0.0776
120	202.5	48.76	0.18	0.00045	0.01387	0.31	9.69	0.002512	0.0775

Trim Drag vs. Velocity

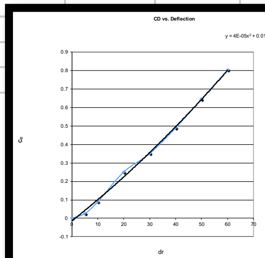
Use calculated C_{Lv} to obtain δr off the developed graph



Airspeed (ref)	Windmilling engine inlet drag	Windmilling engine nozzle drag	Total Engine Drag	one engine thrust	side force required	lift per vertical stabilizer/rudder	CLv required of each vertical stabilizer	from CLv vs dr graph	CD, wrt vertical planform area	Trim drag from vertical(s) and rudder(s)	Total drag
V	D_{E-inl}	D_{E-noz}	D_E	T	$L_{v\ req}$	$L_{v\ per\ v\text{-}stab}$	C_{Lv}	δr	C_{Dv}	D_{trim}	D_{total}
knots	lbf	lbf	lbf	lbf	lbf	lbf				lbf	lbf
60	3.8	118.6	122.5	22800	1719.7	859.9	0.56	9.25	0.09260	282.2	404.6
70	5.2	161.4	166.6	22560	1705.2	852.6	0.41	6.4	0.05918	245.5	412.1
80	6.8	210.7	217.5	22320	1691.2	845.6	0.31	4.7	0.03955	214.3	431.8
90	8.6	266.5	275.1	22200	1686.8	843.4	0.25	3.8	0.02926	200.6	475.7
100	10.6	328.7	339.4	22080	1682.9	841.5	0.20	3	0.02016	170.7	510.0
110	12.9	397.5	410.3	22020	1684.0	842.0	0.16	2.4	0.01337	137.0	547.3
120	15.3	472.6	487.9	21960	1685.7	842.9	0.14	2.1	0.00999	121.7	609.7

Used goal seek to get a more accurate δr

Goal seek for dr	
CLv	0.14
dr	2.089
from CLV vs dr graph best fit eq	
x3	1.00E-05
x2	-1.40E-03
x1	0.0734
x0	-0.0072



coefficients from CD vs dr graph curve fit equation	
x2	0.00004
x1	0.0111
x0	-0.0135

Use curve fit to get equation to calculate C_{Dv} from δr required

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