

Flight Tests of Fuel Saving Formation Flight in General Aviation.

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FOI*



Formation Flight

Flight mechanics, Logistics and Fuel savings

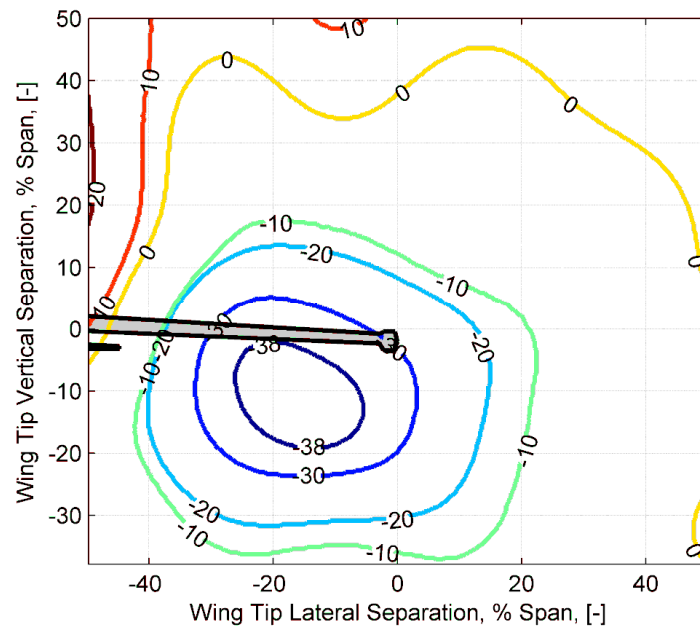
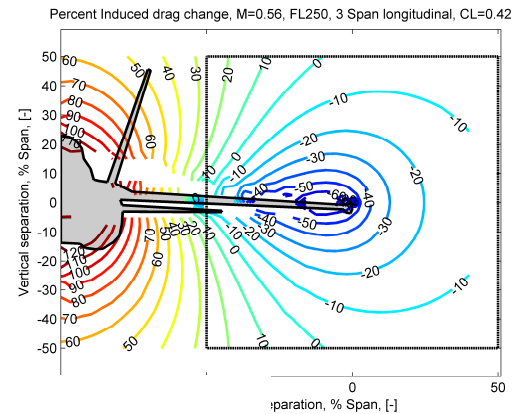
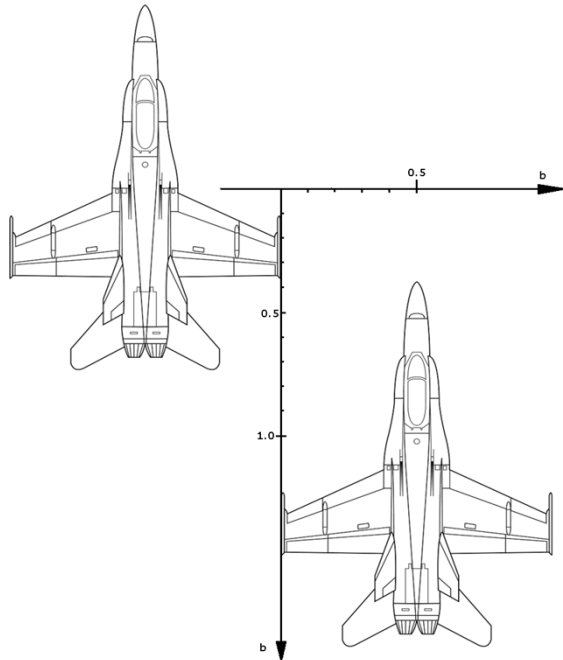


- *Can we model drag reduction due to formation flight with accuracy using a vortex lattice method? –Yes!*
- *Thin wings*
- *Small angles of attack*
- *Incompressible*
- *Inviscous*
- *No wake relaxation*

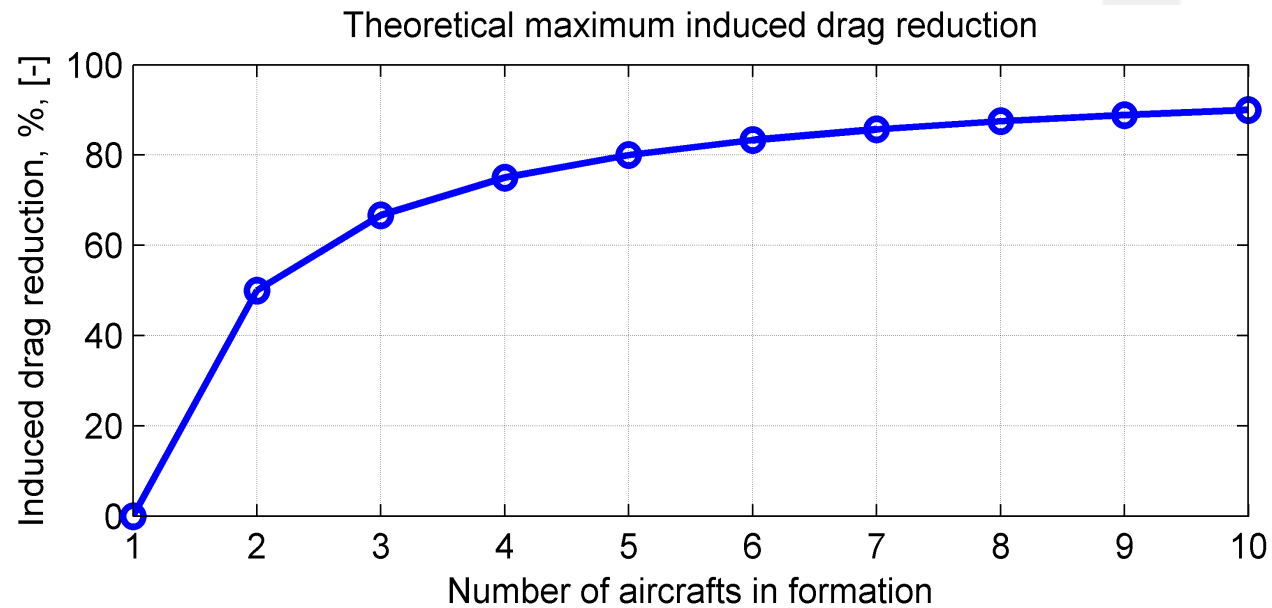


Code Validation

(CEAS2013)



Effects on induced drag

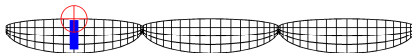
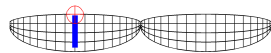
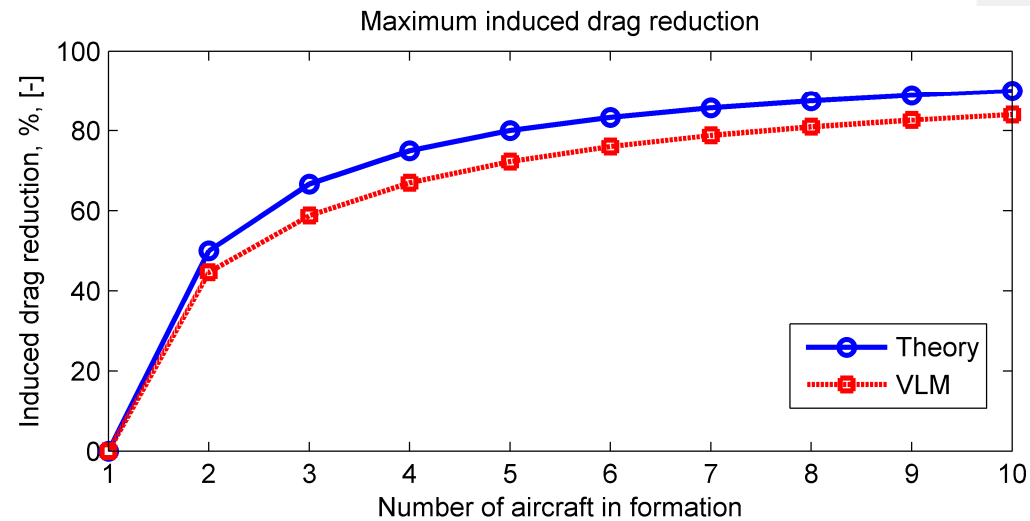


$$C_{Di} = \frac{C_L^2}{\pi e \cdot AR}$$

$$C_{Di,2} = C_{Di,1} \frac{AR_1}{AR_2}$$

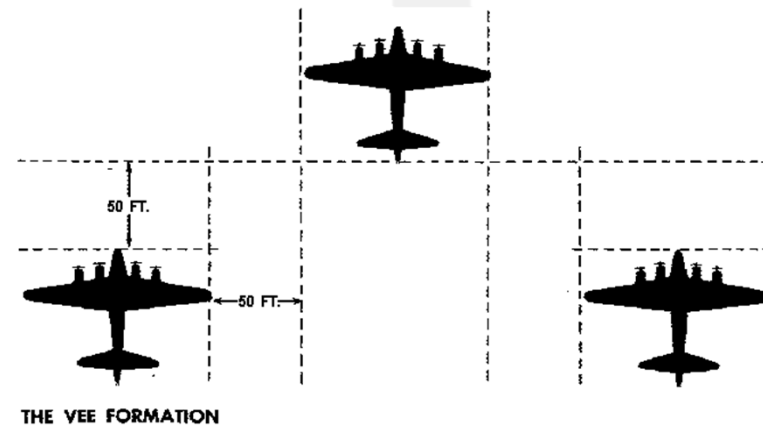
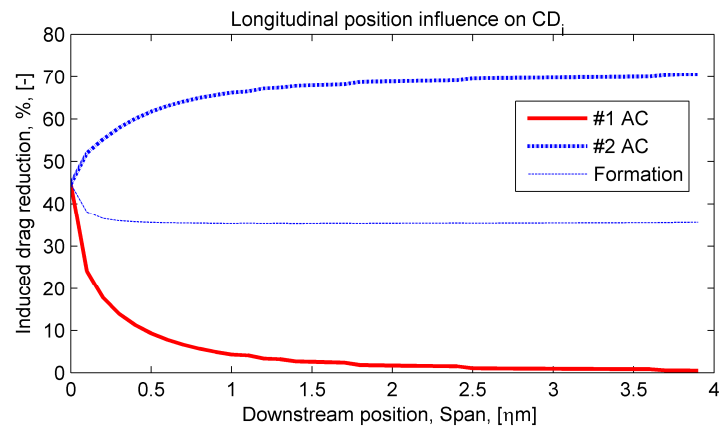
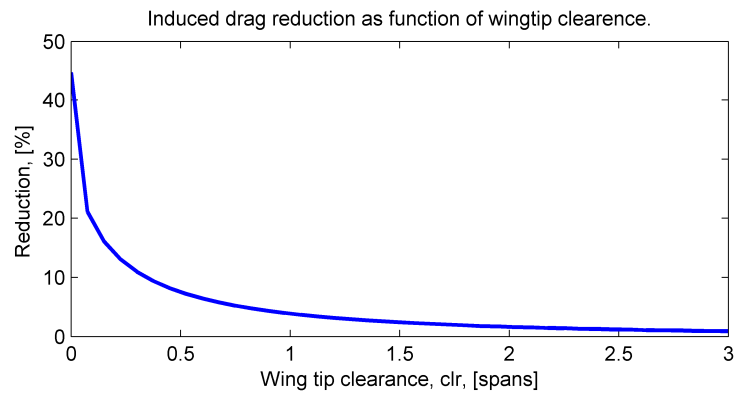
$$S = \left(1 - \frac{1}{n}\right) \cdot 100$$

Effects on induced drag



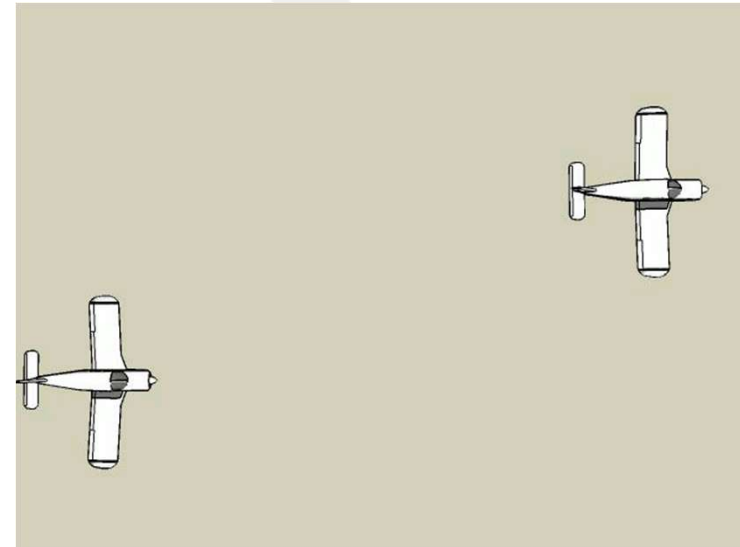
0				
45	45			
46	84	46		
48	87	87	46	
49	89	89	89	49

Effect of spanwise tip separation



Test Setup

- Aircraft:
 - Piper PA-28 181 ARROW 2
 - Full fuel load, 2 pilots.
970 kg
- Formation
 - 2.75 Span Longitudinal Separation
 - 0.9 Span lateral, 0.1 Vertical
 - 2000 ft, 75 kts. (CL = 0.7)



Test plan

– 3 Flights

- Tare
- Formation
- Solo

– Full fuel

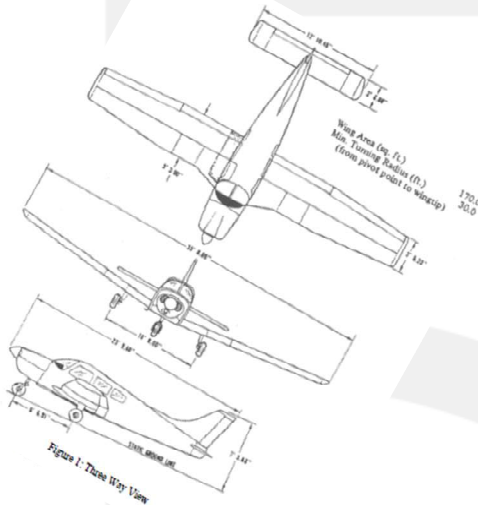
- Calibrated bowser

1.2 ENGINES	
(a) Number of Engines	1
(b) Engine Manufacturer	Lycoming
(c) Engine Model Number	C-180
(d) Rated Horsepower	180
(e) Rated Speed (RPM)	2700
(f) Stroke (inches)	3.125
(g) Displacement (cubic inches)	4.75
(h) Compression Ratio	8.5:1
(i) Engine Type	4-Cylinder, Horizontally Opposed, Direct Drive, A/E Cooled

1.5 OIL	
(a) Oil Capacity (U.S. Quarts)	5
(b) Oil Specification	15W-50
(c) Oil Viscosity per Average Ambient Temp. for Starting	

MLL-1-2002	
SAE Grade	MLL-1-2002
–	–
00	15W-50 OR 20W-50
10	00
20	00
30	30
40	40
50	50
60	60
70	70
80	80
90	90
100	100
110	110
120	120
130	130
140	140
150	150
160	160
170	170
180	180
190	190
200	200
210	210
220	220
230	230
240	240
250	250
260	260
270	270
280	280
290	290
300	300
310	310
320	320
330	330
340	340
350	350
360	360
370	370
380	380
390	390
400	400
410	410
420	420
430	430
440	440
450	450
460	460
470	470
480	480
490	490
500	500
510	510
520	520
530	530
540	540
550	550
560	560
570	570
580	580
590	590
600	600
610	610
620	620
630	630
640	640
650	650
660	660
670	670
680	680
690	690
700	700
710	710
720	720
730	730
740	740
750	750
760	760
770	770
780	780
790	790
800	800
810	810
820	820
830	830
840	840
850	850
860	860
870	870
880	880
890	890
900	900
910	910
920	920
930	930
940	940
950	950
960	960
970	970
980	980
990	990
1000	1000

If the operating temperatures on the published pages, use the lighter grade oil.



Tare Flight

- Tare Flight
 - TO,
 - climb,
 - round beacon Sturefors,
 - descend,
 - land.



Formation Flight

- Formation Flight

- TO

- Climb

- Sturefors,

- Valdemarsvik,

- Falerum,

- Sturefors,

- Descend,

- Land



Instrumentation



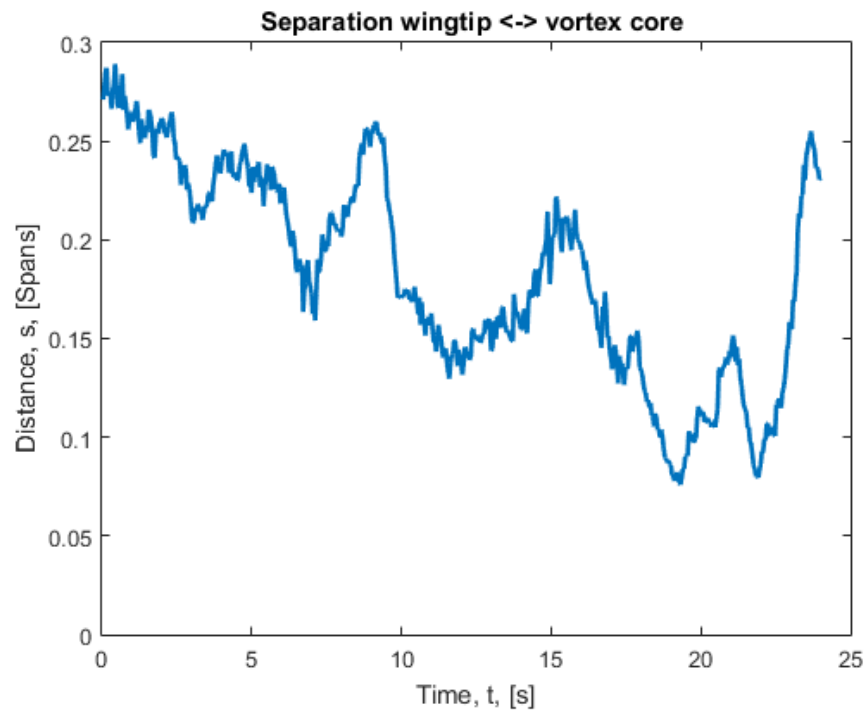
Deviations from plan





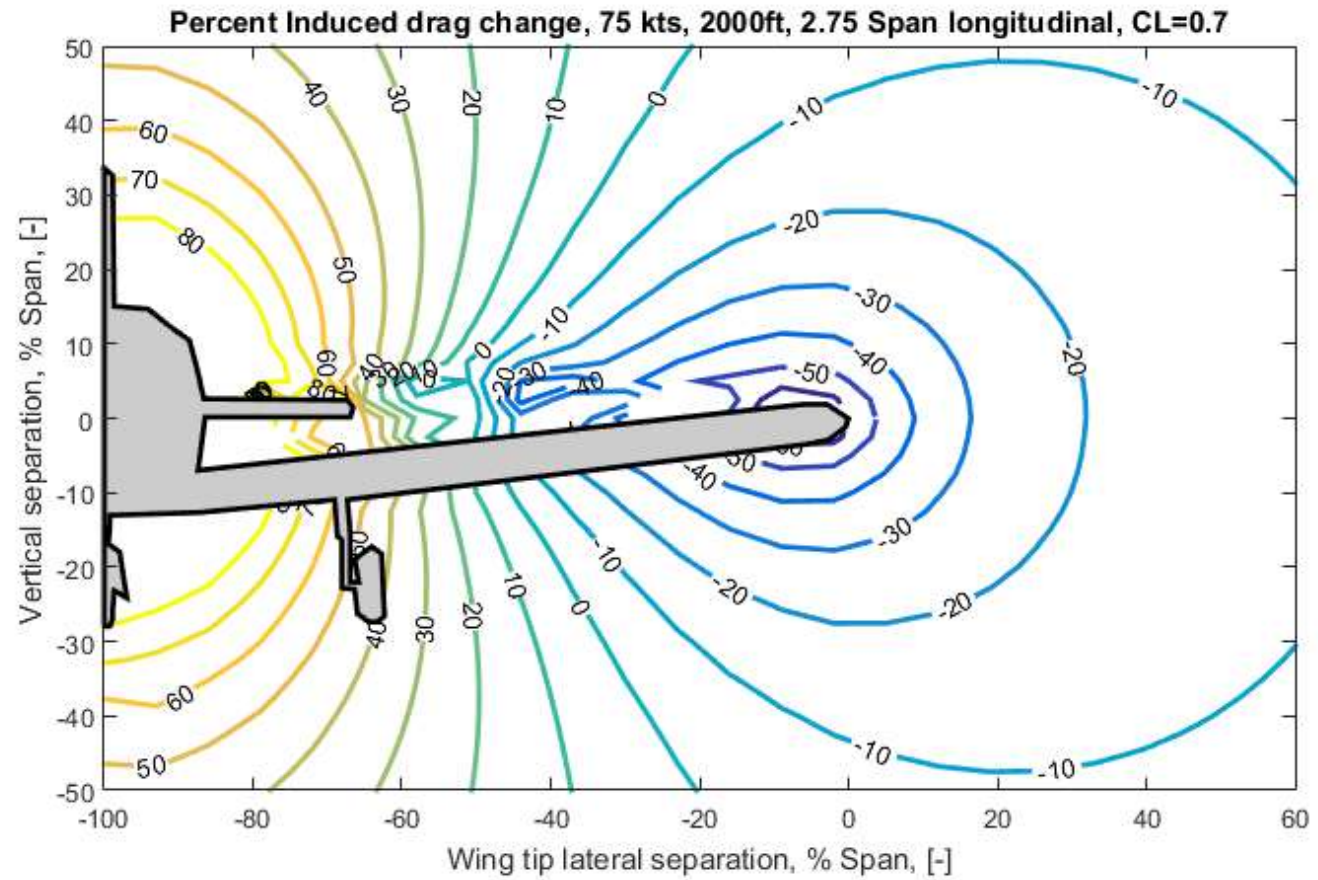
Assorted results

- Average 0.2 Span

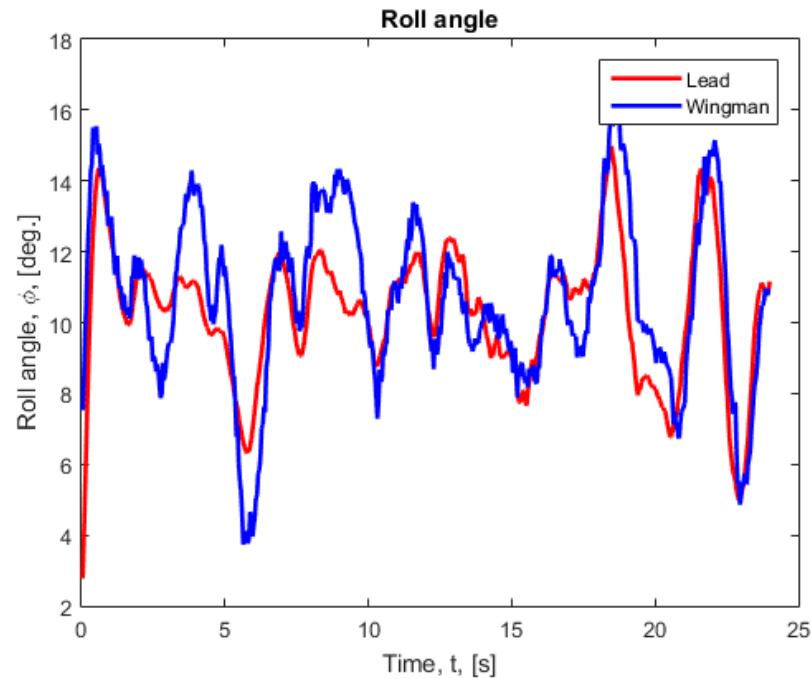


PA28 Simulated data

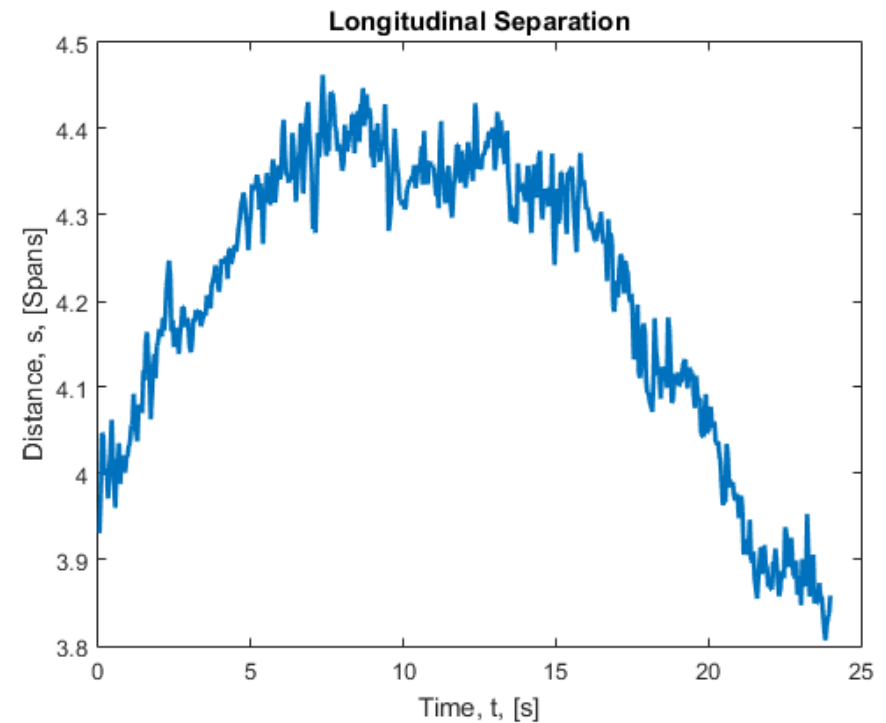
$D_i = 0.4 D$



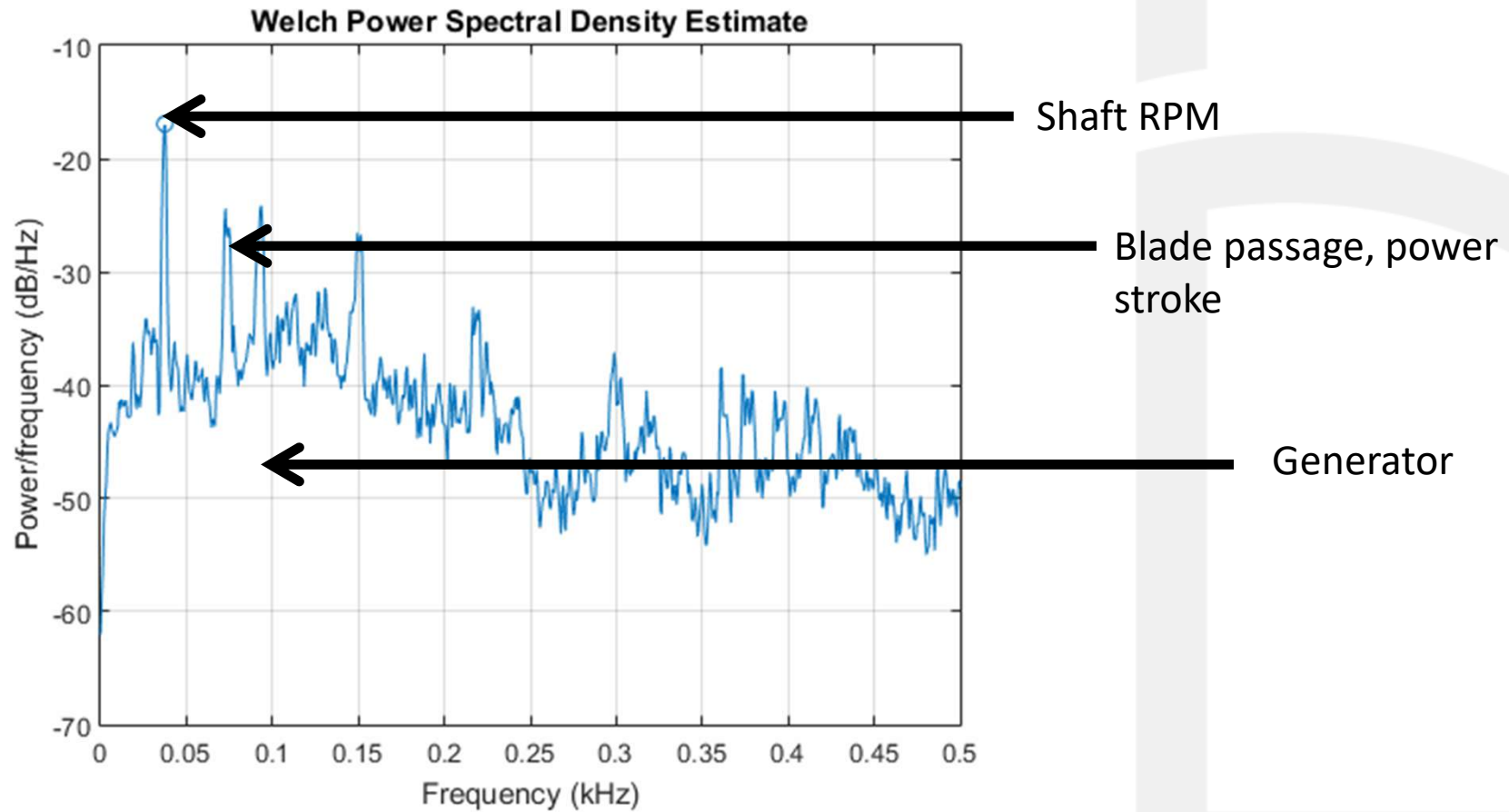
Assorted results



- Pilots comments

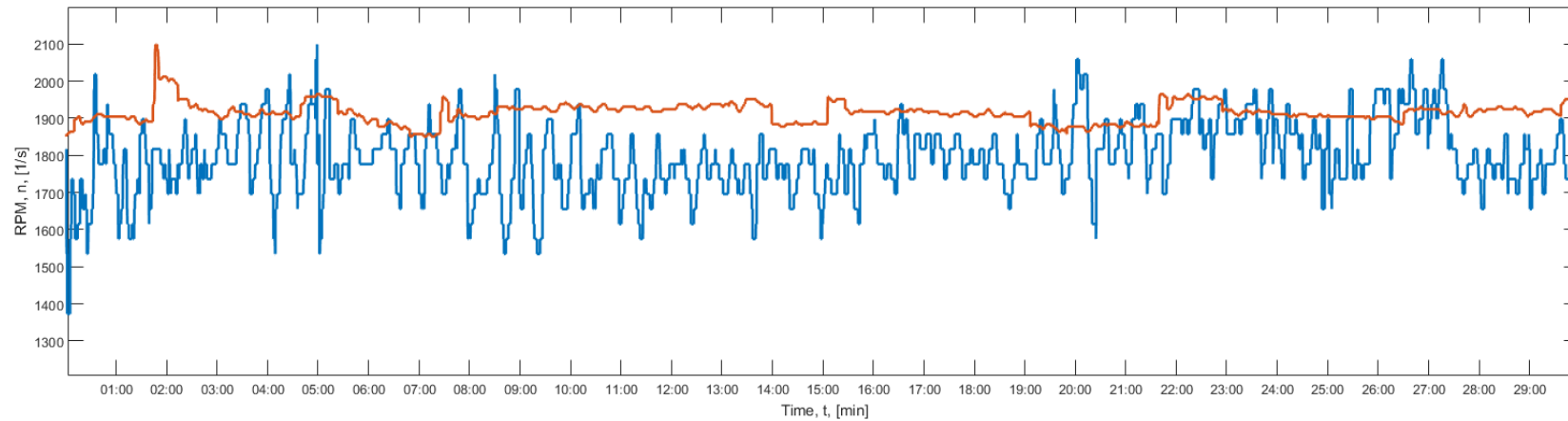


Throttle change



Difference in rpm

SOLO / **WINGMAN**



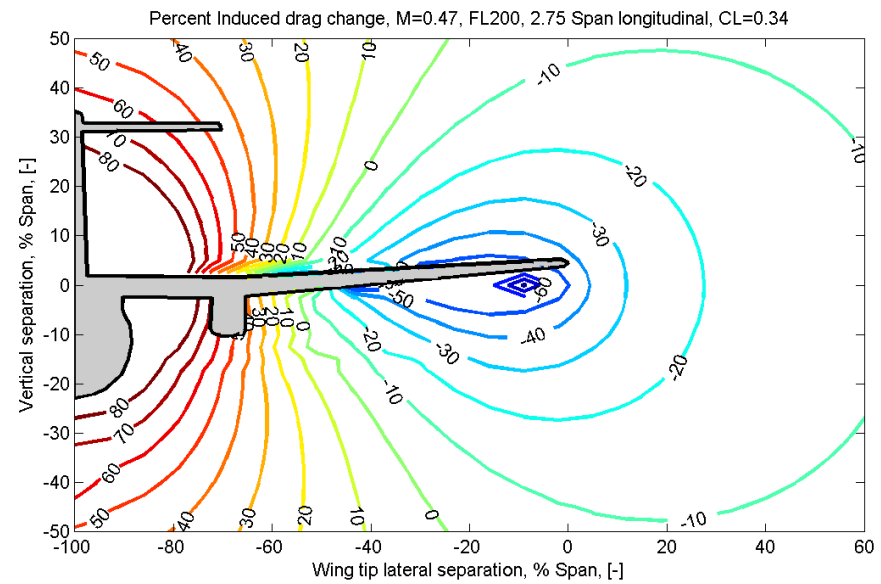
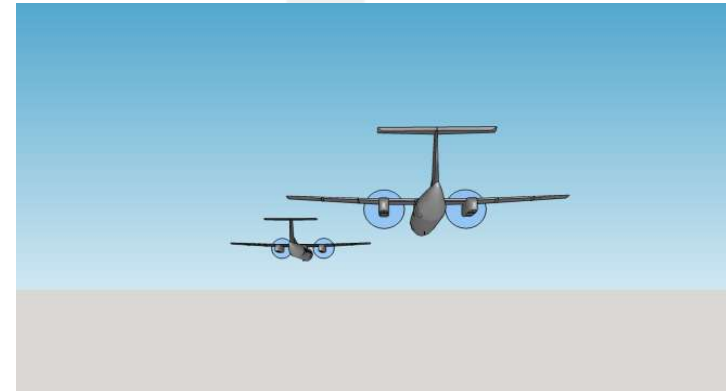
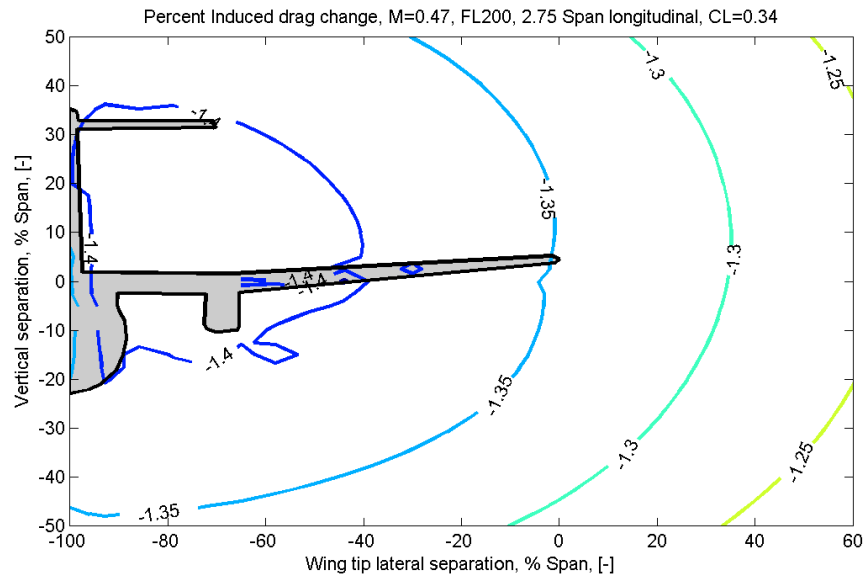
Compliance

- **COMMISSION REGULATION (EU) 2015/1039**
amending Regulation (EU) No 748/2012 as regards flight testing
 - Out of Scope.
- **Skyddslag (2010:305), Lag (2016:319) om skydd för geografisk information.**
 - Avbildningstillstånd från skyddsobjektägaren, spridningstillstånd från lantmäteriet.
- **Deviation from ‘best practice’:**
 - Flight test engineer also project manager
 - Mitigation: PIC informed.
- **Finance, internal.**
 - Research plan not externally vetted.
 - Mitigation: Enhanced Internal Review.

Thank you for your attention!

Questions?

Commercial Application

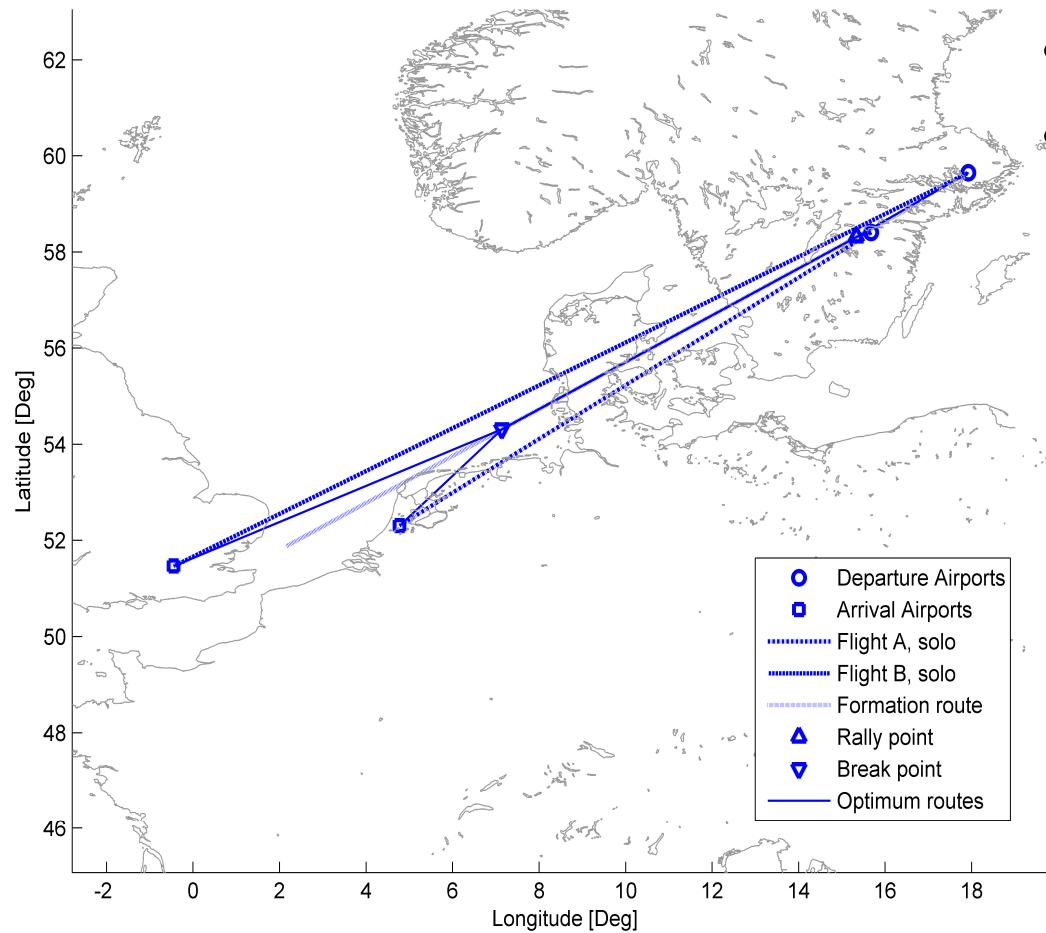


Total Drag results. [dcts]

	Baseline	Formation	Reduction
CD_i	35	21	40%
CD_0	139	139	0
Total	174	166	8%
L/D	19.5	20.7	

Operational Logistics

Merging Separate Routes



- Stockholm – London
- Linköping – Amsterdam

SL +0.4 % cost
LA -1.2 % cost

SL +1.3% distance
LA +0.3% distance

SL 45% in formation
LA 70% in formation