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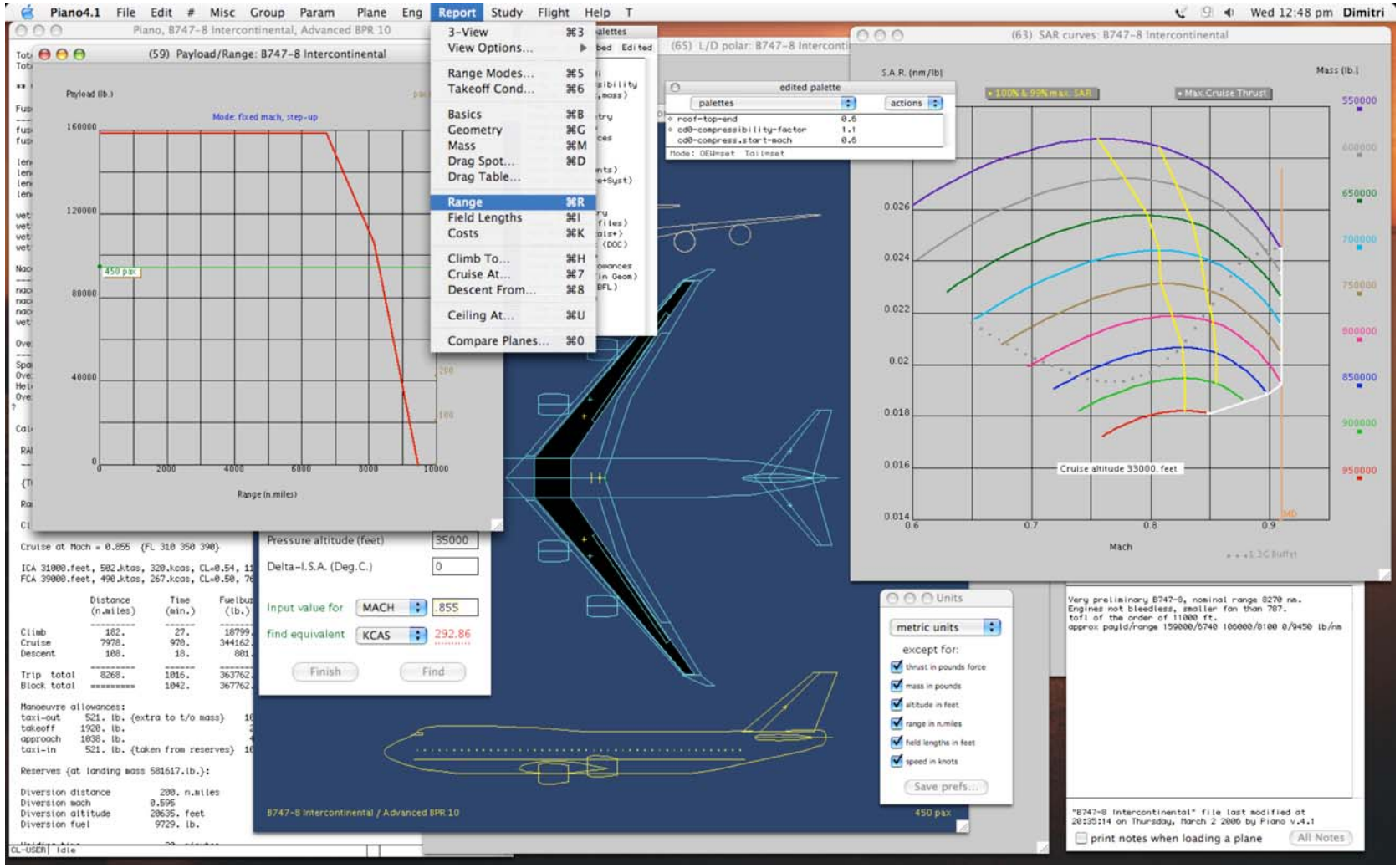
Piano presentation to CAEP WG2 TG2, Rome 2006

Dimitri Simos



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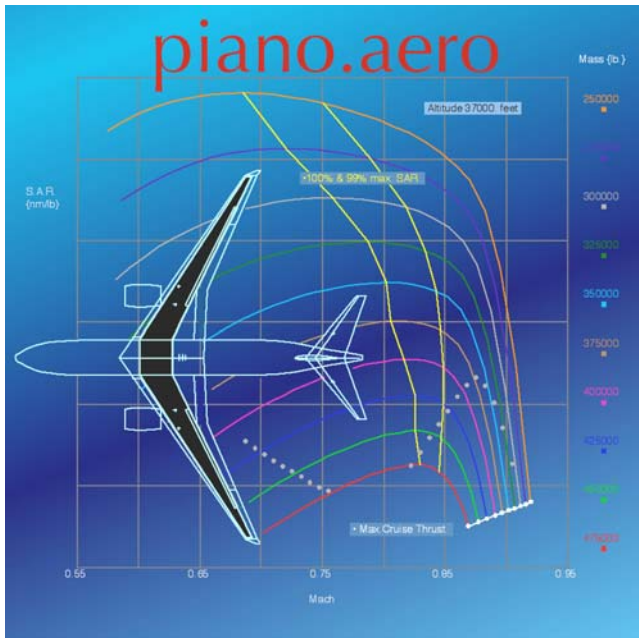

A tool for:

- Preliminary Design – New aircraft from scratch
- Competitor Evaluation – Aircraft Database / user's own models
- Performance Analysis – From first principles (emissions from fuelflow)

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About Lissys & Piano

- A (pre) history:

  Mid-80s Origins: PhD, postdoc research (SHORTS, SERC)

  Late 80s: “Rapide” precursor (RR a/c projects dept)

  Early 90s: Lissys Ltd formed, 1st Piano customer (Airbus)

  By 2006: 23+ organisations using Piano worldwide.

- Most customers by word-of-mouth.

- Piano is the sole product of Lissys.

- Lissys has no connections to other organisations.
  It is 100% independent.

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Piano Users

(name at time of purchase)

- Rolls Royce plc (Derby)
- Airbus Industrie (Toulouse)
- Boeing (Seattle)
- McDonnell Douglas
  (Long Beach, pre-Boeing merger)
- UK Department of Trade and Industry
- UK Ministry of Defence
- Allison Engines (now RR USA)
- BMW Rolls-Royce GmbH
  (now RR Deutschland)
- De Havilland (Bombardier)
- SHORTS (Bombardier)
- SNECMA (SAFRAN group)
- Korean Aerospace Research Institute
- MTU - Motoren und Turbinen Union
- Samsung Aerospace
- Daewoo Heavy Industries
- IPTN
  (PT. Industri Pesawat Terbang Nusantara)
- EUROCONTROL (Bretigny sur Orge)
- Fairchild Dornier
- FFA (now FOI),
  the Aeronautical Research Institute of Sweden
- QinetiQ (ex DERA)
- AVIC 1 (Aviation Industries of China)
- First Aircraft Institute of AVIC 1
  (Shanghai)
- Pratt & Whitney Canada

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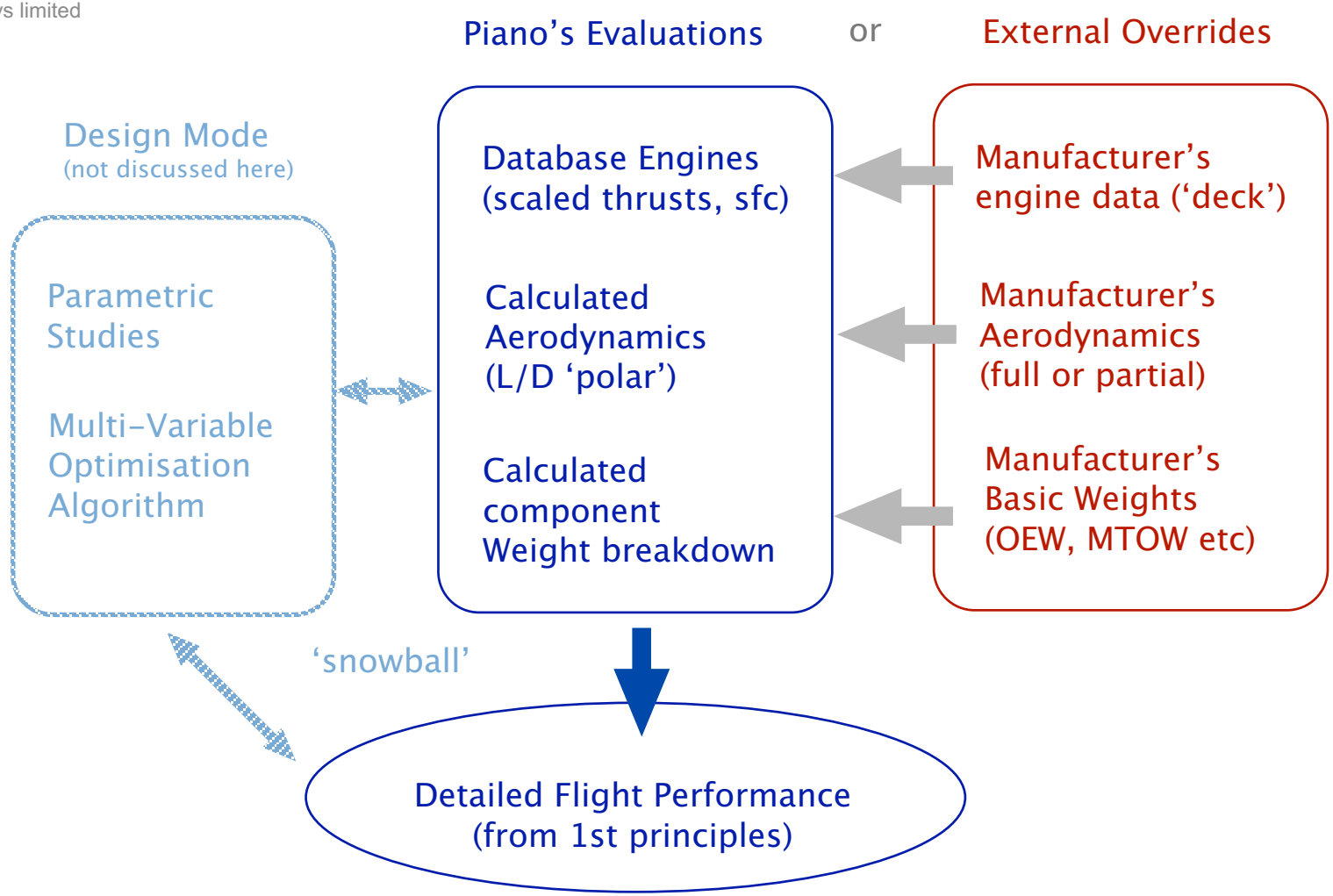
Flexibility



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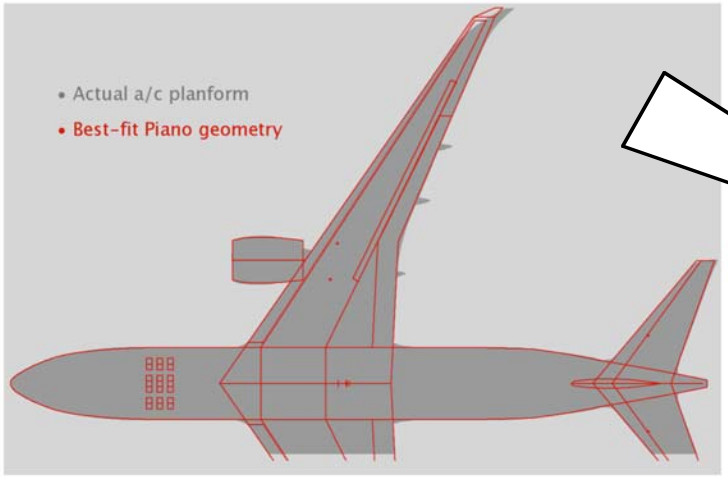
Modelling an existing (/ projected) aircraft in Piano

Based on:

- Best available basic Geometry (3-views)
- Basic design weights: MTOW, OEW*, MZFW, MLW (* if quoted)
- Design range, other known (/ claimed) performance
- Technology-level selections & tuning:
  aero (compressibility etc), engine standards



- One compact 'plane file':
  typically ~ 60-90 parameters,
  max ~ 260, min 20.
- All subsequent analyses and performance generated by Piano - on demand & solely from this file.

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Piano's extensive database: 250+ aircraft

Aerospatiale AS100
Aerospatiale AS100ER
Aerospatiale AS125
Aerospatiale AS125ER
AI(R) 58
AI(R) 70
Airbus A3XX-50R
Airbus A3XX-100
Airbus A3XX-100R
Airbus A3XX-200
Airbus A300 600R
Airbus A300 B2-200
Airbus A310-200
Airbus A310-300
Airbus A318 basic
Airbus A319 basic
Airbus A319 option
Airbus A320-200 basic
Airbus A320-200 option
Airbus A321-100
Airbus A330-200 230t
Airbus A330-300 230t
Airbus A340-200 275t
Airbus A340-300 271t
Airbus A340-500 (v03)
Airbus A340-500 (v05)
Airbus A340-600 (v03)
Airbus A340-600 (v05)
Airbus A350-800
Airbus A350-900
Airbus A380-800 (v02)
Airbus A380-800 (v03)
Airbus Corporate Jetliner
Airbus Mil A400M
Antonov An-70T
Antonov An-124 Ruslan
Antonov An-124-210
Antonov An-148-100
Antonov An-148-200
ARJ-21 (AVIC1) 05
ATR 42
ATR 72
Avro RJ 85 basic
Avro RJ 85 option
Avro RJ-70
Avro RJ-100
Avro RJ-115
B707-320C
B717-200 BGW
B717-200 HGW
B717-200 spec00
B727-200A
B737-200
B737-300 (basic)
B737-300 (option)
B737-400 (basic)
B737-400 (option)
B737-500 (basic)
B737-500 (option)
B737-600 (NG basic)
B737-600 (NG option)
B737-700 (NG basic)
B737-700 (NG basic)w
B737-700 (NG option)
B737-700ER (w)
B737-800 (NG basic)
B737-800 (NG basic)w
B737-800 (NG option)
B737-900 (NG option)
B737-900ER (w)
B737-BBJ1
B737-BBJ2
B747-200B
B747-400 mfrspec
B747-400 stretch
B747-500X (dec96)
B747-600X (dec96)
B747-8 Intercontinental
B747-init100
B747-SP
B747X
B747X Stretch
B757-200 basic
B757-200 option1
B757-200 option2
B757-300
B767-200 basic
B767-200ER
B767-300
B767-300ER
B767-300ER option
B767-400ER(X)
B777-200 A (506)
B777-200 A (515)
B777-200 A (535)
B777-200 B (580)
B777-200 B (590)
B777-200 ER (IGW)
B777-200 LR (v04)
B777-300 (632)
B777-300 (660)
B777-300 ER (v04)
B787-3 (shrink)
B787-8 (baseline)
B787-9 (stretch)
BAe 125-700
BAe 125-800
BAe 1000
BAe ATP
BAe Jetstream 41
BAe NRA
Beech King Air 200
Beechjet 400A
Boeing 7E7 baseline
Boeing 7E7 stretch
Boeing Business Jet
Boeing model 763-246C
Boeing model 763-246CER
Boeing model 763-246CS
Bombardier BRJ-X-90
Bombardier BRJ-X-110
Bombardier C 110ER
Bombardier C 110STD
Bombardier C 130ER
Bombardier C 130STD
Bombardier C(04) 110ER
Bombardier C(04) 110ST
Bombardier C(04) 135ER
Bombardier C(04) 135ST
Bombardier Continental
C-17 test
Canadair CRJ 200ER
Canadair CRJ 200LR
Canadair CRJ 700
Canadair CRJ 700ER
Canadair CRJ 900
Canadair CRJ 900ER
Canadair CRJ 900LR
Canadair RJ 100
Canadair RJ 100ER
Cessna Citation III
Cessna Citation V
Cessna CitationJet1
Cessna CitationJet2
Cessna Sovereign
Cessna X
Challenger 300
Challenger 601-3A
Challenger 604
Dash 8 Series 100
Dash 8 Series Q200
Dash 8 Series Q300
Dash 8 Series Q400 HGW
Dassault Falcon 7X
Dassault Falcon 900 C
Dassault Falcon 900 EX
Dassault Falcon 2000
Dassault Falcon 2000EX
Dassault Falcon 9000
Dornier 328
Dornier 328JET
Dornier 428JET
Douglas DC 9-14
Douglas DC 9-34
Douglas DC 10-10
Douglas DC 10-30
Douglas MD-81
Douglas MD-82-88
Douglas MD-83 auxCap
Douglas MD-87
Douglas MD-90-30
Douglas MD-90-50
Douglas MD-95 Tay
Eclipse 500 spec04
Eclipse spec00
Embraer 170 basic
Embraer 170 LR
Embraer 175 basic
Embraer 175 LR
Embraer 190 basic
Embraer 190 LR
Embraer 195 basic
Embraer 195 LR
Embraer EMB-120
Embraer EMB-135
Embraer EMB-145
Euroflag FLA turbofan
FA-X-100
FA-X-100ER
FA-X-200
FA-X-200ER
FA-X-300
FA-X-300ER
FAAB-Mriya
Fairchild Dornier 528JET
Fairchild Dornier 728JET
Fairchild Dornier 928JET
Fokker F50 Srs 100
Fokker F70 basic
Fokker F70 option
Fokker F100 basic
Fokker F100 option
Fokker F130 basic
Fokker F130 option
Fokker-F28 Mk4000
Global 5000
Global Express (02)
Global Express (x99)
Gulfstream G IV
Gulfstream G IV-SP
Gulfstream G V
Gulfstream G V-SP
Honda HondaJet
IAI 1125 Astra
IAI Galaxy G200
Ilyushin IL-62M
Ilyushin IL-96-300
Ilyushin IL-96M
JADC YSX75
KARI-100seater
Learjet 31A
Learjet 31A ER
Learjet 45
Learjet 55C
Learjet 60
Lockheed L-1011-200
Lockheed L-1011-500
MD-11 basic
MD-11 option
MD-12 HC
MD-12X
MD-17 Globemaster
MD-XX (spec91)
NLA sample
NSA (G1)
NSA (G2)
NSA (G3)
NSA (G4)
Raytheon Beechjet 400A
Raytheon Hawker Horizon
Raytheon Premier 1
Regioliner R92
Rombac 1-11 ReEng
Saab 340B
Saab 2000
Shorts FJX
Sino Swearingen SJ30-2
Sukhoi-IL RRJ 60B
Sukhoi-IL RRJ 60LR
Sukhoi-IL RRJ 75B
Sukhoi-IL RRJ 75LR
Sukhoi-IL RRJ 95B
Sukhoi-IL RRJ 95LR
Swearingen SJ30 original
Tupolev Tu-154M
Tupolev Tu-204-220
Tupolev Tu-334-100
Tupolev Tu-334-200
Tupolev Tu-334-200Str
Yakovlev Yak-42M
Yakovlev Yak-46PF

Conventional, Commercial, Subsonic.

Small BJs (Eclipse) to A380 + developments (2.5T to 560T+)

Turbofans, turboprops, geared fan, propfan..

Existing & Projected – From historical (B707) to current 'hot topics': A350, B787, A380, B737-700ER & 900ER, RRJ, C-series, B747-8..

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Aircraft database calibration

- Notes for each a/c give indications of confidence levels:
  - Best calibrations: Complete aerodynamics ('polar'), actual engine data, flight tested performance (nice but rare!)
  - Good calibrations: Independent backfigured aero 'spot' data, generic engine adjusted to typical cruise or climb. (tech brochures, manuals)
  - Best-guesses: Presumed technology levels from similar a/c (e.g. Jane's, press, marketing 'glossies')
- All database models can be easily modified.
- Existing & projected a/c compared by the same standards.
- No approval by any manufacturer sought or implied.
- Reflects 15-year effort, continually reviewed.

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Aerodynamic validation

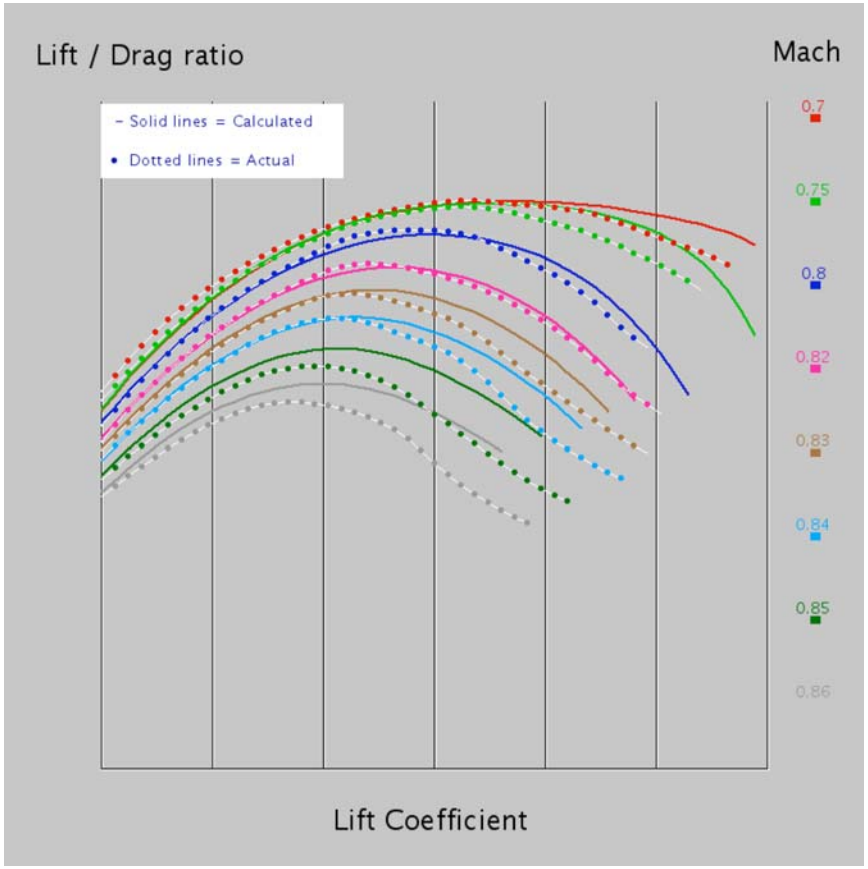
Aerodynamic calculations based on calibrated, industry-derived classical drag-buildup methods

C_{Do}, C_{Di}, $C_{Dcompres.}$, C_{Dtrim}

$C_D = f(C_L, Mach, Re)$

- More than 10 complete 'drag polars' for real a/c support Piano's models.
- Countless 'backfigured' drag points used in calibration and tuning of plane files.

Lift/Drag 'polar' curves for a Mach 0.8 widebody twin turbofan a/c



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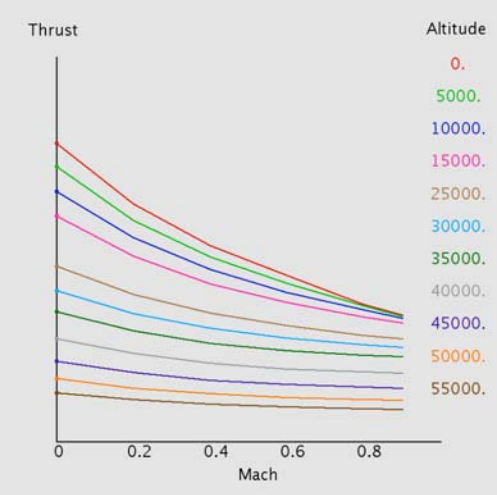
Engines represented by data matrices

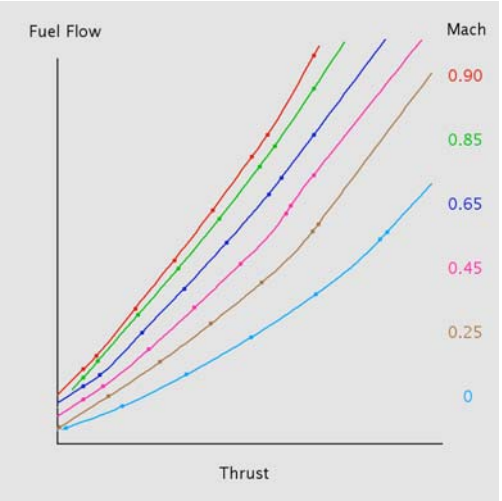
- Scaleable to any thrust ('rubber' engs)
- More than 30 models in database (actual in-service, some simulations)
- Can read new engines from manufacturer's 'decks'.



Each engine contains data for:

- Thrust ratings (max climb, max cruise, etc)
- Fuel flow (or sfc) characteristics (full or compact data, various altitudes)
- Idle thrust & idle fuel flow

User can adjust all of the above individually.



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Flight performance calculated from first principles

(stepwise integration of basic performance equations)

Confidence in
Aerodynamics ('polar')

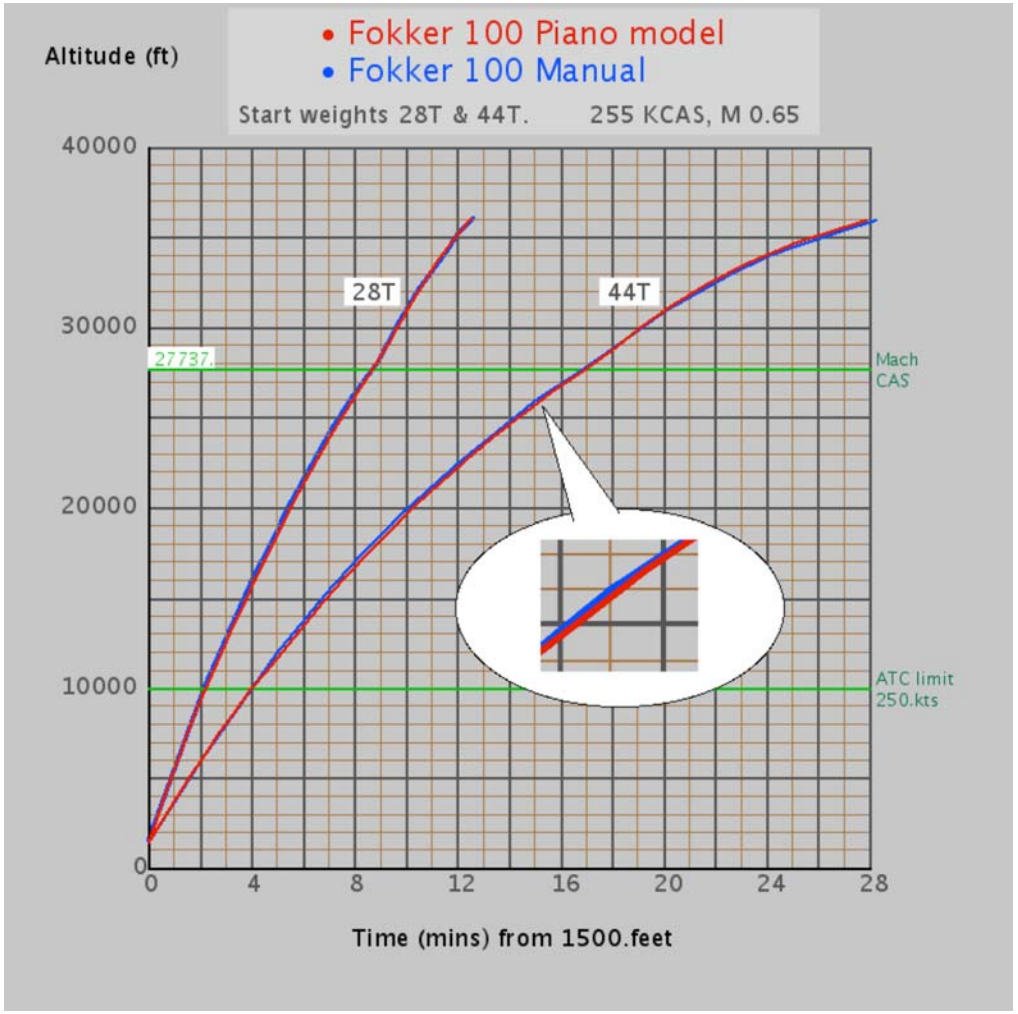
+

Confidence in
Engine Model

=

Accurate Predictions
of Flight Performance,
concensus between
performance tools.

simply
Newton!



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Because Piano generates a **physically meaningful model*** of the aircraft, tuning it to match actual performance at representative points is natural, transparent, and results in good agreement over a broader range of operating conditions.

Result: Fuel usage is evaluated reliably, not deduced from brochure-reading and curve-fits.

* Defined by its physical properties and identifiable technological standards, not as a set of abstract fitted coefficients.

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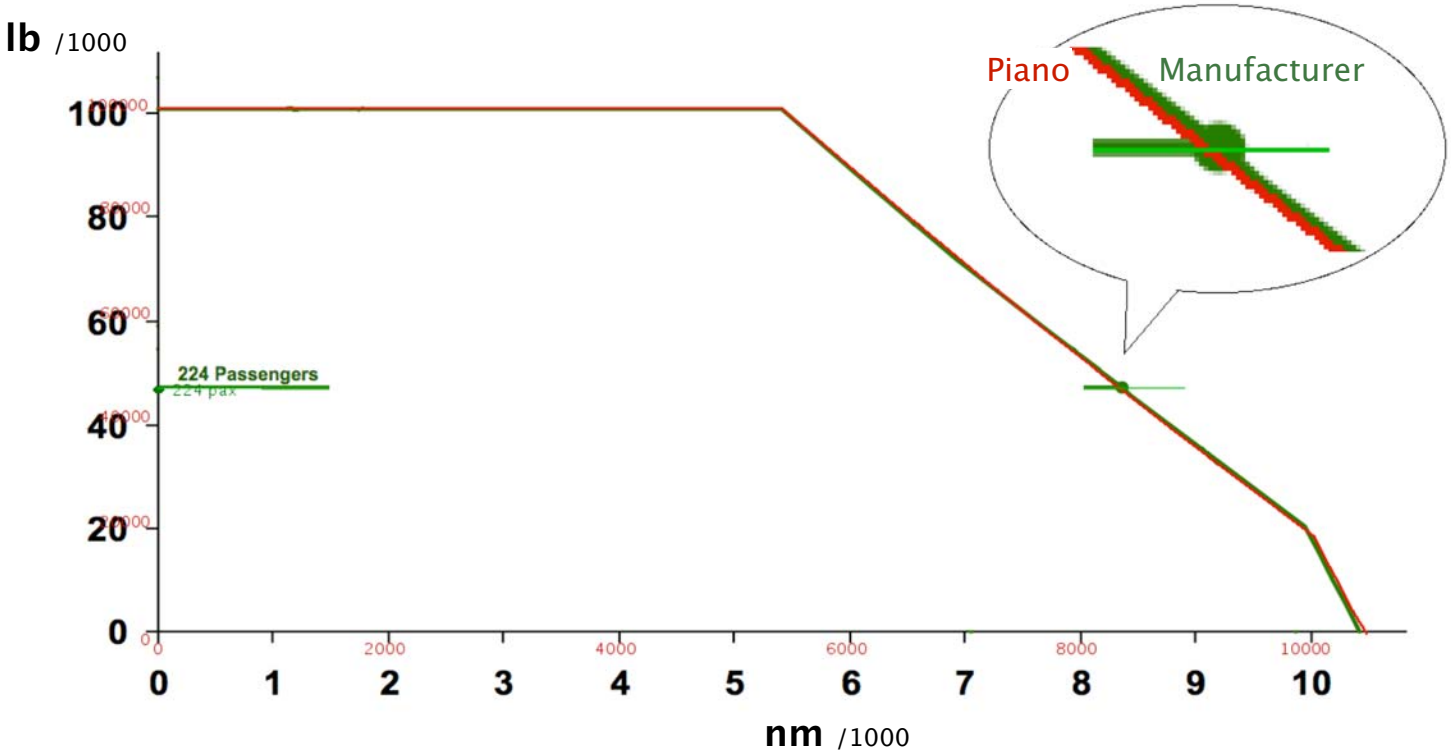
Validation:

Superposition of Manufacturer's & Piano's payload-range diagrams: Piano model tuned to match range @ design point.

(Published prelim. data for projected Mach 0.85 twin)



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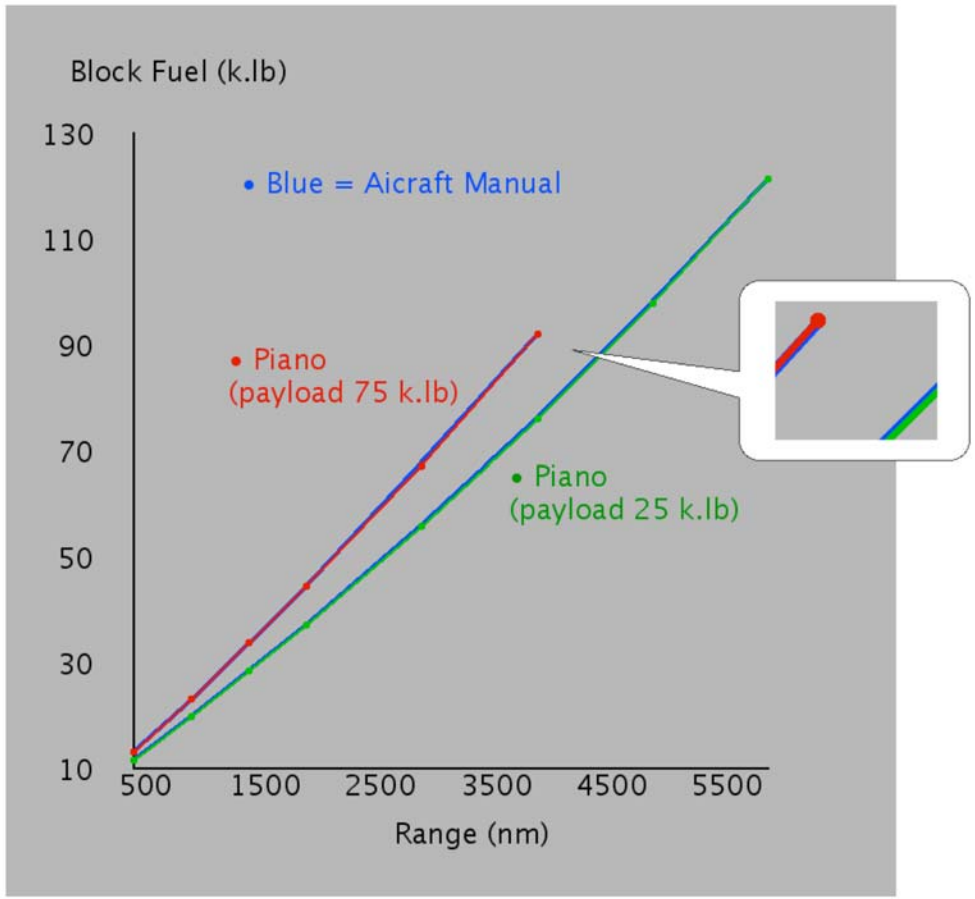
Validation:

Manufacturer's & Piano's fuel burn:
Piano model tuned to match range @ design point.

(Mach 0.8 widebody twin)



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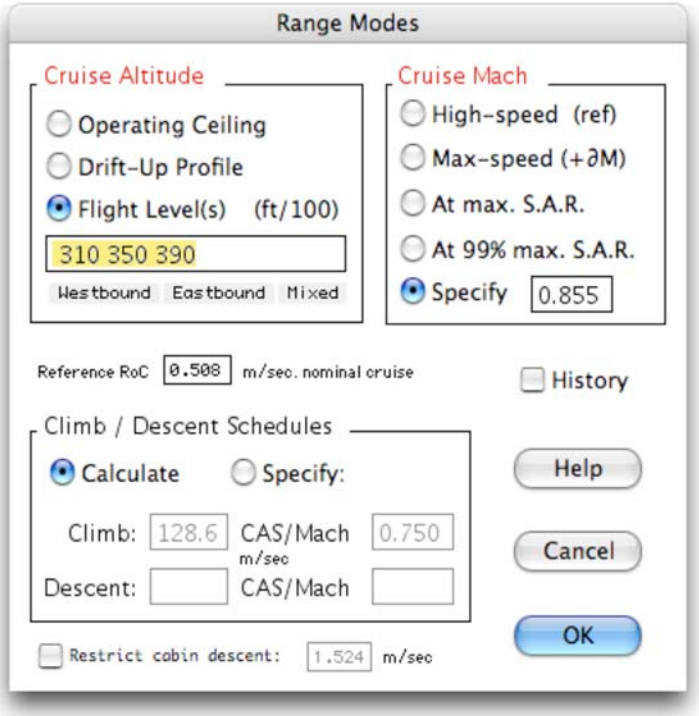
Integrated mission analysis

- Fast & accurate calculations of fuel usage & distribution
- Missions @ any block distance or weight

- Climb (250kt lim, CAS, Mach)
- Multi-step cruise altitude selection, Cruise Mach (LRC, hispeed, input)
- Descent, (RoD, pressurisation limits)
- Reserves (diversion, hold, contingency) (Intl, Shorthaul Euro/US, NBAA-IFR...) allowances (taxi out, t/o, app, taxi in)
- Boeing-2 emissions method (NOx, HC, CO)



- Statistical adjustments for in-service deterioration, off great circle routing are up to the user, as always!

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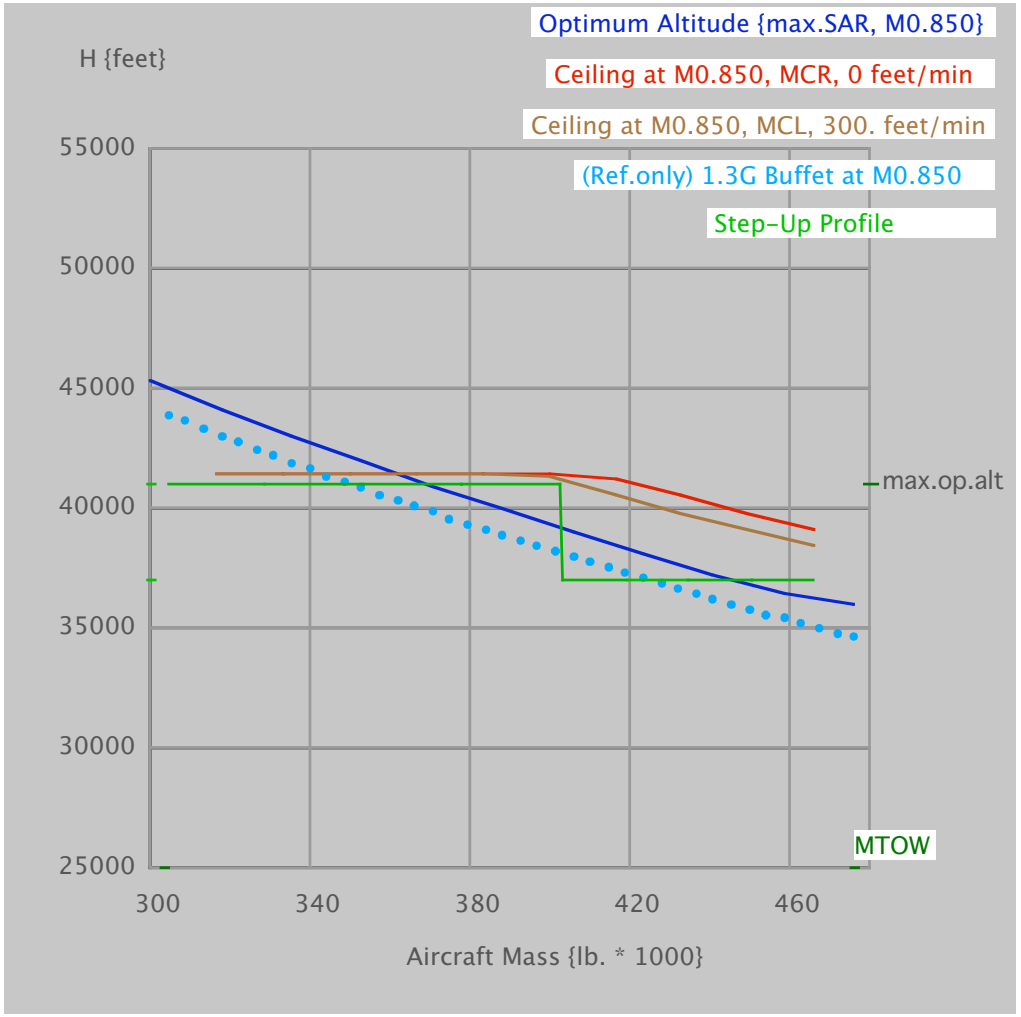
Optimum step-cruise altitude selection



Integrated mission summary

```
RANGE REPORT  {design}

{TOW 476000.lb./ OEW 239200.lb./ Fuel 189760.lb./ Payload 47040.lb.}
Range mode: fixed mach, step-up cruise
Climb schedule: 250./ 277.kcas/ mach 0.825 above 35738.feet
Cruise at Mach = 0.850  {FL 370 410}
ICA 37000.feet, 488.ktas, 278.kcas, CL=0.53, 11186.lbf./eng=MCR-12%
FCA 41000.feet, 488.ktas, 253.kcas, CL=0.42, 7690.lbf./eng=MCR-26%

             Distance        Time      Fuelburn
             (n.miles)      (min.)      (lb.)
             _________      ______     _______
Climb           181.          28.        9529.   {S.L to ICA}
Cruise         8034.         989.      161751.   {ICA to ICA}
Descent         129.          22.         476.   {ICA to S.L}
             _________      ______     _______
Trip  total    8345.        1039.      171756.
Block total  =========      1057.      174613.

Emissions: taxi,t/o  climb   cruise  descent  app,taxi   total
(lb.NOx)     30.3    148.4   1798.2      1.1      2.6   1980.4
(lb.HC)      0.16     0.56    19.20     0.69     0.26    20.87
(lb.CO)       4.8      7.0    481.3     16.8      6.6    516.4

Manoeuvre allowances:
taxi-out    2000. lb. {extra to t/o mass}    10.0 min.
takeoff      458. lb.                         1.0 min.
approach     263. lb.                         2.0 min.
taxi-in      137. lb. {taken from reserves}   5.0 min.

Reserves {at landing mass 303524.lb.}:

Diversion distance          200. n.miles
Diversion mach            0.535
Diversion altitude        22117. feet
Diversion fuel             5040. lb.
Holding time                 30. minutes
Holding mach              0.276
Holding altitude           5000. feet
Holding fuel               3620. lb.
Contingency fuel           8624. lb. {5.% of mission fuel}
Total Reserve fuel        17284. lb.
```

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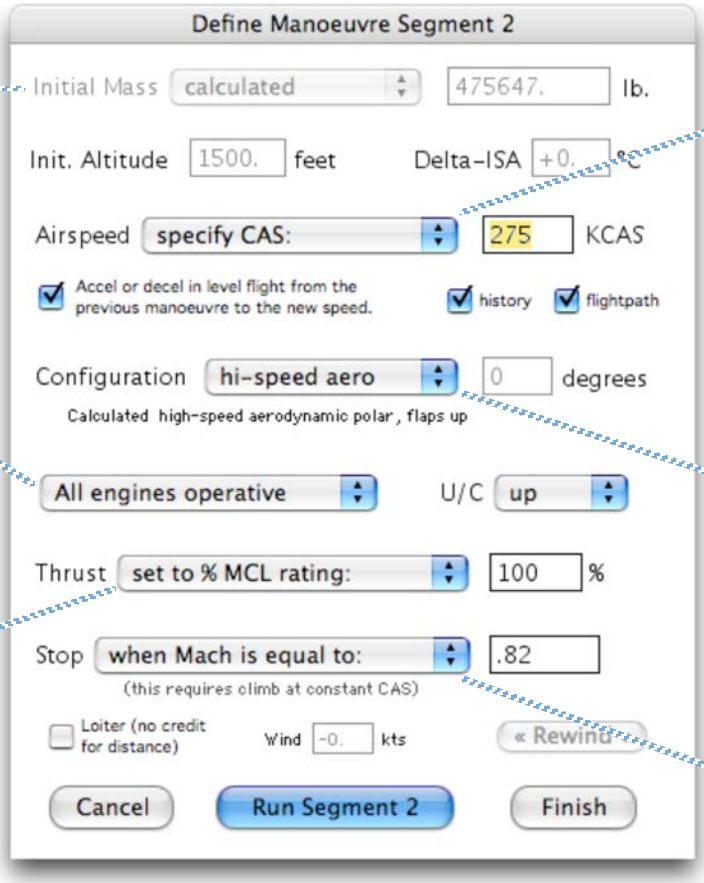
Flight Manoeuvres & Sequences

FMS



✓ specify:
MTOW
MLW
normal landing
mid cruise (typ.)

✓ All engines operative
One engine inoperative

emergency-2nd.seg.
✓ set to % MTO rating:
set to % MCO rating:
set to % MCL rating:
set to % MCR rating:
set to idle
idle, deploy % spoilers:

to match ± flightpath°:
to match ± climb rate:
to match cabin dp/dt:
to maintain level flight
to maintain level cruise

V2 safety speed
✓ V3 all eng takeoff
specify % of Vstall:
Vapp final approach

specify CAS:
for best gradient
for max rate of climb
for max roc, < ATC
for minimum drag
keep the same CAS

specify Mach:
Mach for max SAR
Mach for 99% SAR
keep the same Mach

max in level flight

✓ takeoff flap:
landing flap:
arbitrary flap:
hi-speed aero

when altitude changes by:
✓ when altitude is equal to:
when time elapsed is:
when mass reduces to:
when distance covered is:

after 1 point calculation

when Mach is equal to:
when CAS is equal to:
when ready to stepup by:

Define, run, go to next...

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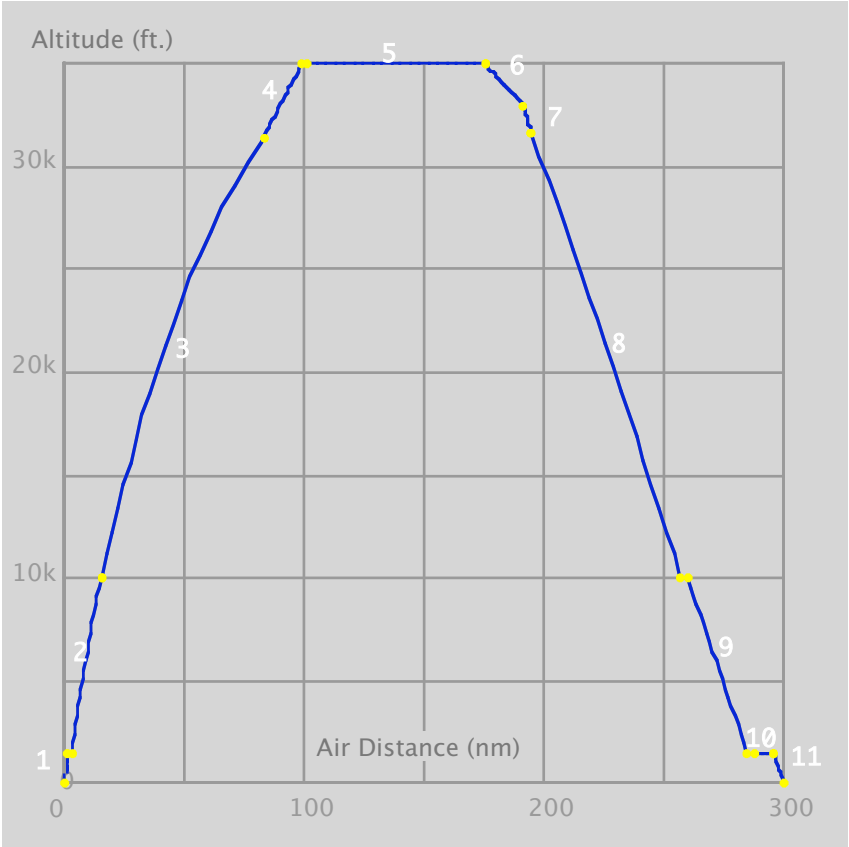
Manoeuvre Sequences: A “performance microscope”



- Not limited to ‘standard’ block missions
- Complete or partial flight profiles
- Individual manoeuvres can be edited
- Segments added or removed
- Iterated to match end conditions (time, distance, weight)
- Saved on file
- Re-played / re-wound
- Highly detailed o/p (incl. accel/decel between segments)
- For LTO cycle flight segments

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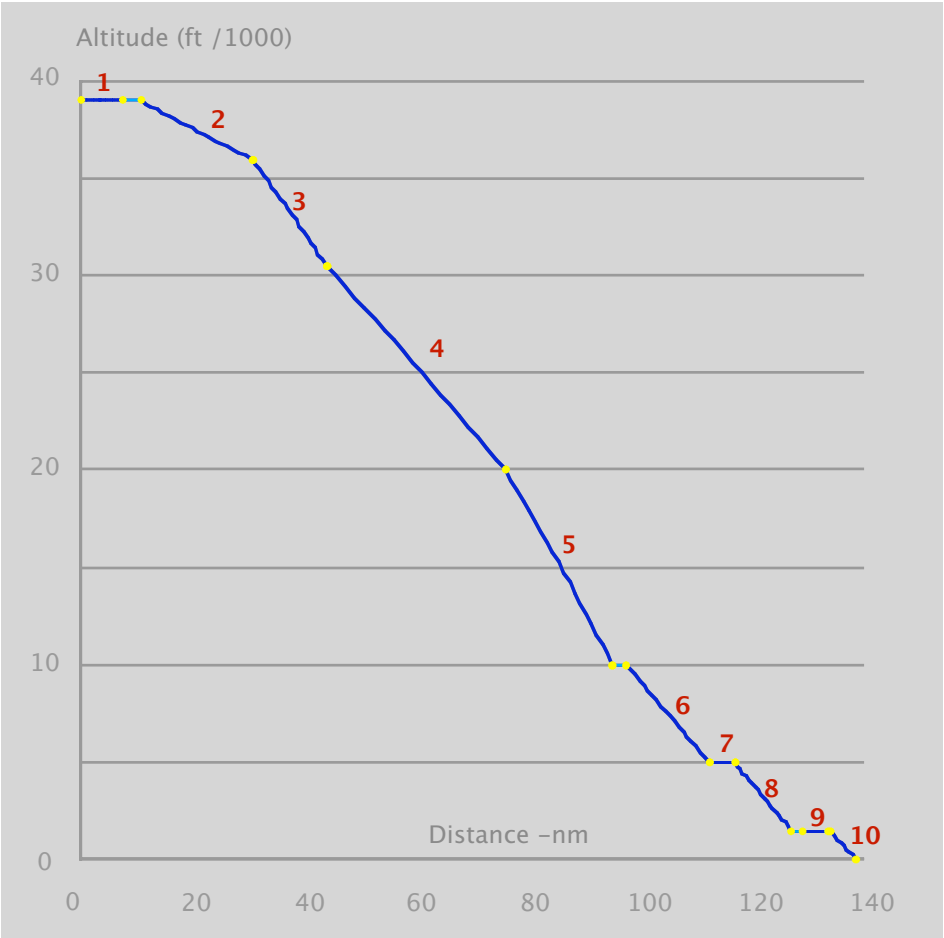
Example Sequence (arbitrary descent)



1. Cruise, 1 min, @ M.8
   & decel to M.75
2. 300 fpm dp/dt descent to FL360
3. idle descent @ M.75 until:
4. idle descent @ 280 kcas
5. 3000 fpm @ same kcas to
   FL100, then decel to 250 kts
6. idle descent @ 250 kcas
7. 1 min level hold @ 5000 ft
8. idle descent @ 250 kcas
   & decel to:
9. 1 min hold, flaps 15, 150%Vs
   u/c down & decel to:
10. Vapp, flaps 35, 3-deg slope
    to 50 ft threshold.

Mass at (1) iterated to match required landing mass at (10).

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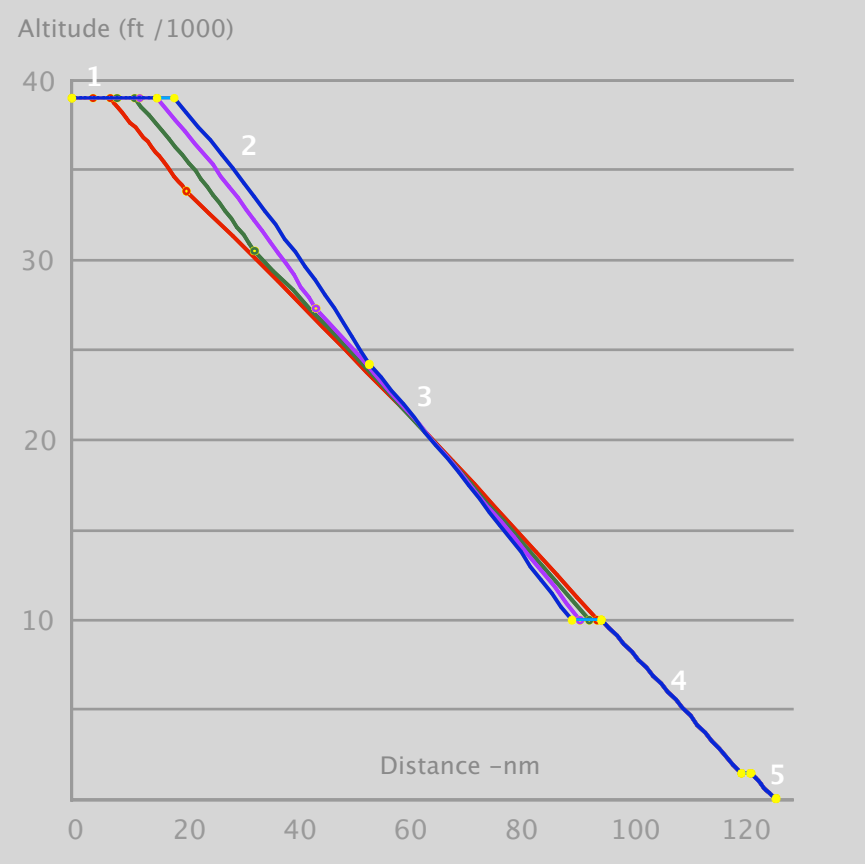
Example Sequences (effects of descent speed)



Segments:

1 Cruise @ M.8
2 Idle descent @ M.75
3 Idle descent @ kcas shown below
4 Idle descent @ 250kts
5 Approach @ Vapp

Fixed Total Distance = 127 nm

Seg. 3 speed	Totals (lb) Fuel	NOx	HC	CO
260 kcas	666.8	3.11	0.721	11.25
280 kcas	691.8	3.31	0.683	10.78
300 kcas	715.6	3.50	0.654	10.43
320 kcas	735.9	3.65	0.633	10.18

Sample output

B787-8 design range

Initial segment details

```
Manoeuvre segment 1 starts at:

Initial Mass          476000.  lb.  (CL 1.18 wimpress)
Initial Altitude          35.  feet
Delta-ISA                 +0.  °C
Airspeed (CAS)           175.  kts  (V3)
Flaps                     10   deg.
Undercarriage             up
All eng.operative
Thrust per engine      50066.  lbf. (100% MTO)

Climb/Descent rate      2566.  feet/min
Flightpath angle         8.2   deg. (grad.14.44%)
True airspeed            175.  kts
Fuel Flow rate         37128.  lb/hr
NOx emission rate      810.7   lb/hr
HC  emission rate      1.109   lb/hr
CO  emission rate        2.4   lb/hr
L/D ratio              16.58
Total aircraft drag    28710.  lbf.

Segment 1 ends at total time = 0.6 mins, endmass = 475647.lb.

         Altitude   Time   Distance   Fuel Burn    NOx     HC      CO
           feet      sec    n.miles      lb.        lb.     lb.     lb.

Increm:   +1465.   +34.7    +0.00     +352.7    +7.63   +0.011   +0.02
Final :    1500.    34.7     0.00      352.7     7.63    0.011    0.02
-------------------------------------------------------------------------
History:    Alt    Time      Dist      Burnt    FN/eng   CAS    Mach    RoC    Drag    TAS
             35.     0.0    0.000        0.0    50066.   175.   0.265   2566.  28710.  175.
            198.     3.8    0.000       39.2    49880.   175.   0.266   2559.  28709.  176.
            361.     7.6    0.000       78.5    49695.   175.   0.267   2551.  28707.  176.
            523.    11.5    0.000      117.7    49509.   175.   0.268   2543.  28706.  177.
            686.    15.3    0.000      156.9    49323.   175.   0.268   2535.  28705.  177.
            849.    19.2    0.000      196.1    49138.   175.   0.269   2527.  28703.  178.
           1012.    23.0    0.000      235.2    48953.   175.   0.270   2519.  28702.  178.
           1174.    26.9    0.000      274.4    48768.   175.   0.271   2511.  28701.  178.
           1337.    30.8    0.000      313.6    48583.   175.   0.271   2503.  28700.  179.
           1500.    34.7    0.000      352.7    48398.   175.   0.272   2495.  28698.  179.
```


```
Acceleration to 250.kts in level flight at 1500.feet ≈0.14g:
Time +28.1 sec, Dist +1.70 n.miles, Fuelburn +282.1 lb.
NOx  +6.16 lb., HC +0.009 lb., CO +0.018 lb.

Manoeuvre segment 2 starts at:

Initial Mass         475365.  lb.  (CL 0.58 wimpress)
Initial Altitude       1500.  feet
Delta-ISA                +0.  °C
Airspeed (CAS)         250.   kts  (input)
Flaps                    0    deg. (hi-speed)
Undercarriage           up
All eng.operative
Thrust per engine     38146.  lbf. (100% MCL)

Climb/Descent rate     2726.  feet/min
Flightpath angle        6.0   deg. (grad.10.54%)
True airspeed           255.  kts
Fuel Flow rate        32246.  lb/hr
NOx emission rate     607.4   lb/hr
HC  emission rate     1.135   lb/hr
CO  emission rate       1.7   lb/hr
L/D ratio             21.52
Total aircraft drag   22088.  lbf.

Segment 2 ends at total time = 4.5 mins, endmass = 473674.lb.

        Altitude   Time   Distance   Fuel Burn    NOx     HC      CO
          feet      sec    n.miles     lb.        lb.     lb.     lb.

Increm:   +8500.   +207.   +15.63    +1690.8   +30.58   +0.067   +0.27
Final :   10000.    270.    17.33     2325.6    44.37    0.086    0.31
-------------------------------------------------------------------------
History:    Alt    Time      Dist      Burnt    FN/eng   CAS    Mach    RoC    Drag    TAS
           1500.    62.8    1.699      634.8    38146.   250.   0.388   2726.  22088.  255.
           1947.    72.7    2.403      723.0    37751.   250.   0.391   2701.  22088.  257.
           2395.    82.7    3.118      811.3    37357.   250.   0.394   2675.  22087.  259.
           2842.    92.8    3.844      899.6    36966.   250.   0.397   2650.  22087.  260
.........
```

etc, etc...

Final segment

(to landing threshold)

```
Manoeuvre segment 11 starts at:

Initial Mass          303851.  lb.  (CL 1.54 wimpress)
Initial Altitude        1500.  feet
Delta-ISA                 +0.  °C
Airspeed (CAS)          123.   kts  (Vapp)
Flaps                    35    deg.
Undercarriage           down
All eng.operative
Thrust per engine      11055.  lbf. (match grad.) ≈23.1%MCL

Climb/Descent rate      -666.  feet/min
Flightpath angle        -3.0   deg. (grad.-5.24%)
True airspeed            126.  kts
Fuel Flow rate          8864.  lb/hr
NOx emission rate       84.3   lb/hr
HC  emission rate      2.383   lb/hr
CO  emission rate       63.2   lb/hr
L/D ratio               7.92
Total aircraft drag    38345.  lbf.

Segment 11 ends at total time = 1041.2 mins, endmass = 303524.lb.

         Altitude   Time   Distance   Fuel Burn    NOx     HC      CO
           feet      sec    n.miles     lb.        lb.     lb.     lb.

Increm:   -1450.   +132.    +0.00     +327.8    +3.11   +0.087   +2.31
Final :      50.  62470.  8344.97   172476.4  1960.72   20.532  504.23
-------------------------------------------------------------------------------
History:    Alt    Time      Dist      Burnt    FN/eng   CAS    Mach    RoC    Drag    TAS
           1500.  62338.    0.000   172148.6    11055.   123.   0.191   -666.  38345.  126.
           1339.  62352.    0.000   172184.5    11055.   123.   0.190   -664.  38341.  125.
           1178.  62367.    0.000   172220.4    11055.   123.   0.190   -663.  38337.  125.
           1017.  62381.    0.000   172256.5    11055.   123.   0.189   -661.  38332.  125.
            856.  62396.    0.000   172292.8    11054.   123.   0.189   -660.  38328.  124.
            694.  62411.    0.000   172329.2    11054.   123.   0.188   -658.  38324.  124.
            533.  62425.    0.000   172365.8    11054.   123.   0.187   -656.  38319.  124.
            372.  62440.    0.000   172402.5    11054.   123.   0.187   -655.  38315.  124.
            211.  62455.    0.000   172439.4    11053.   123.   0.186   -653.  38311.  123.
             50.  62470.    0.000   172476.4    11053.   123.   0.186   -652.  38306.  123.
```

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Thank you!