Dimitri Simos

Piano presentation to CAEP WG2 TG2, Rome 2006
A tool for:

- **Preliminary Design** - New aircraft from scratch
- **Competitor Evaluation** - Aircraft Database / user’s own models
- **Performance Analysis** - From first principles (emissions from fuel flow)
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.
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
Flexibility

Piano’s Evaluations

- Database Engines (scaled thrusts, sfc)
- Calculated Aerodynamics (L/D ‘polar’)
- Calculated component Weight breakdown

or

External Overrides

- Manufacturer’s engine data (‘deck’)
- Manufacturer’s Aerodynamics (full or partial)
- Manufacturer’s Basic Weights (OEW, MTOW etc)

Design Mode (not discussed here)

Parametric Studies

Multi-Variable Optimisation Algorithm

‘snowball’

Detailed Flight Performance (from 1st principles)
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.
Piano’s extensive database: 250+ aircraft

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..
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.
Aerodynamic validation

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

\[ C_{D_{0}}, C_{D_i}, C_{D_{compres}}, C_{D_{trim}} \]

\[ C_{D} = f (C_{L}, \text{Mach}, \text{Re}) \]

- 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
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.
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, consensus between performance tools.

simply Newton!
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.
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)
Validation:

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

(Mach 0.8 widebody twin)
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!
Optimum step-cruise altitude selection

- Optimum Altitude (max.SAR, M0.850)
- Ceiling at M0.850, MCR, 0 feet/min
- Ceiling at M0.850, MCL, 300 feet/min
- (Ref.only) 1.3G Buffet at M0.850
- Step-Up Profile

Aircraft Mass (lb. * 1000)

H (feet)
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.
Flight Manoeuvres & Sequences

Define, run, go to next...
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
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).
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

<table>
<thead>
<tr>
<th>Seg. 3 speed</th>
<th>Fuel</th>
<th>NOx</th>
<th>HC</th>
<th>CO</th>
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<td>300 kcas</td>
<td>715.6</td>
<td>3.50</td>
<td>0.654</td>
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<td>320 kcas</td>
<td>735.9</td>
<td>3.65</td>
<td>0.633</td>
<td>10.18</td>
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</table>
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.

<table>
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<tr>
<th>Altitude (feet)</th>
<th>Time (sec)</th>
<th>Distance (n.miles)</th>
<th>Fuel Burnt (lb)</th>
<th>NOx (lb)</th>
<th>HC (lb)</th>
<th>CO (lb)</th>
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<td>Initial</td>
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<td>+352.7</td>
<td>+7.63</td>
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**History**:

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<th>Altitude (feet)</th>
<th>Time (sec)</th>
<th>Distance (n.miles)</th>
<th>Fuel Burnt (lb)</th>
<th>NOx (lb)</th>
<th>HC (lb)</th>
<th>CO (lb)</th>
<th>CAS (kts)</th>
<th>Mach</th>
<th>RoC (deg./min)</th>
<th>Drag (lbf)</th>
<th>True airspeed (kts)</th>
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<td>175</td>
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<td>0.00</td>
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<td>2495</td>
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<td>179</td>
<td>48138</td>
<td>175</td>
</tr>
</tbody>
</table>

Sample output

**B787–8 design range**

**Initial segment details**
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:

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

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.

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Time</th>
<th>Distance</th>
<th>Fuel Burn</th>
<th>NOx</th>
<th>HC</th>
<th>CO</th>
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<tr>
<td>1500.</td>
<td>62.8</td>
<td>1.699</td>
<td>634.8</td>
<td>38146.</td>
<td>250.</td>
<td>0.388</td>
</tr>
<tr>
<td>1947.</td>
<td>72.7</td>
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<tr>
<td>2395.</td>
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<tr>
<td>2842.</td>
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<td>36966.</td>
<td>250.</td>
<td>0.397</td>
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History:

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<th>Altitude</th>
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<th>Dist</th>
<th>Burnt</th>
<th>FN/eng</th>
<th>CAS</th>
<th>Mach</th>
<th>RoC</th>
<th>Drag</th>
<th>TAS</th>
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<tr>
<td>1500.</td>
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<td>634.8</td>
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<td>899.6</td>
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<td>0.397</td>
<td>2650.22087.260.</td>
<td></td>
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</table>
Manoeuvre segment 11 starts at:

Initial Mass: 303851. lb. (CL 1.54 winpress)
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.)

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.

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Time</th>
<th>Distance</th>
<th>Fuel Burn</th>
<th>NOx</th>
<th>HC</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>feet</td>
<td>sec</td>
<td>n.miles</td>
<td>lb.</td>
<td>lb.</td>
<td>lb.</td>
<td>lb.</td>
</tr>
<tr>
<td>Increm:</td>
<td>-1450.</td>
<td>+132.</td>
<td>+0.00</td>
<td>+327.8</td>
<td>+3.11</td>
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<tr>
<td>Final:</td>
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<td>62470.</td>
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</table>

Final segment (to landing threshold)

History:

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<th>Time</th>
<th>Dist</th>
<th>Burnt</th>
<th>FN/eng</th>
<th>CAS</th>
<th>Mach</th>
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Much more in

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Including

• The entire User’s Guide
• Examples: Gulfstream G550, Boeing 787–8
• Frequently Asked Questions

Thank you!