An International Collaborative Teaching Approach to Aircraft Design Education

INITIAL DESIGN

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IMPROVEMENT

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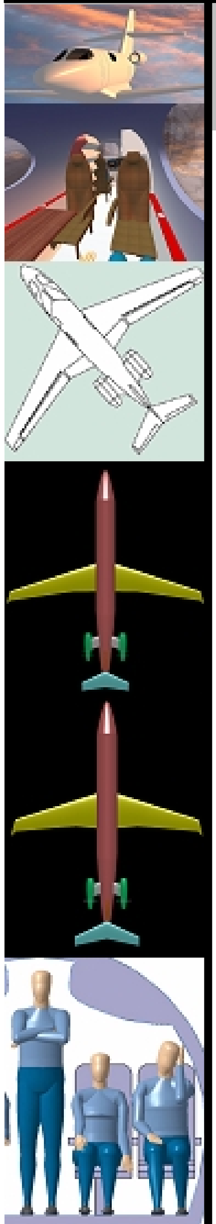


Education Using IPDT-Integrator-Supplier Analogy

Design Education Process

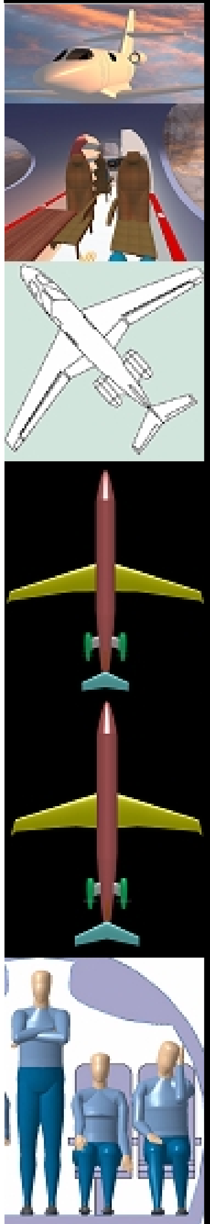
Industry RFP → Present RFP → Prime University Initial Technical Assessment / Collaborating Uni. Initial Technical Assessment → Prime ITA Hand-off → Prime Uni. Refinement / Collaborating Uni. Refinement

Product Development Process

Conceptual Design Phase	Preliminary Design Phase

- MR&O — Systems Architects
- JTAP — Systems Analysts
- Feasibility Study Review
- JCDP — Systems Analysts Integrator+Suppliers
- Specification Review
- Launch

- Contemporary product development is done **collaboratively**, the mechanism is the Integrated Product Development Team (IPDT)
  - Comprises professionals from the aircraft integrator & suppliers
  - Use this approach as an exemplar for aircraft design education
- Marketing Requirements & Objectives (**MR&O**)
  - In industry, it is a set of design specifications
  - Issued as a Request for Proposal (RFP) to the universities



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Feasibility Study Review

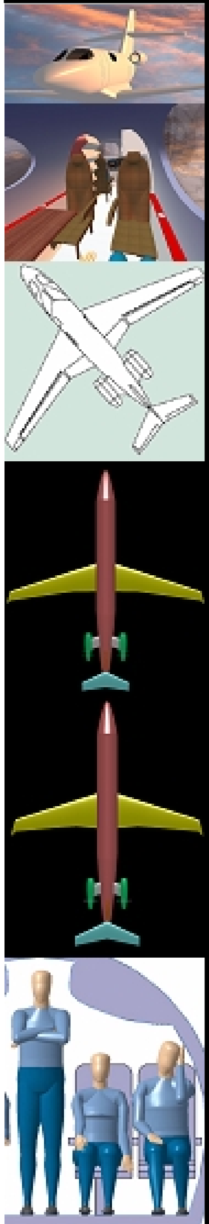
JCDP — Systems Analysts Integrator+Suppliers

Specification Review

Launch

- Joint Technical Assessment Phase (**JTAP**)
  - In industry, involves pooling together a select group of specialists & conceptual designers for a more detailed assessment
  - Collaborative protocol amongst universities begins to gain momentum – hand-off of Prime University Initial Technical Assessment (ITA) to Collaborating University
  - Collaborating University can assume the role as “specialist” here

Education Using IPDT-Integrator-Supplier Analogy



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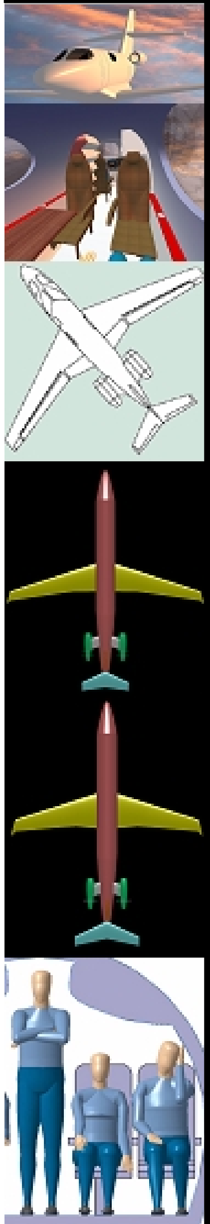
Product Development Process

Conceptual Design Phase					Preliminary Design Phase	
MR&O	JTAP	Feasibility Study Review	JCDP	Specification Review		Launch
Systems Architects	Systems Analysts		Systems Analysts Integrator+Suppliers			

- Joint Conceptual Definition Phase (**JCDP**)
  - In industry, this phase involves potential suppliers & risk-sharing partners, along with the aircraft manufacturer’s system integrators they further develop the basic system architecture & functionality
  - Nearing the milestone of closing out the collaborative aircraft design education
  - Once completed, lessons learned are cycled back to universities

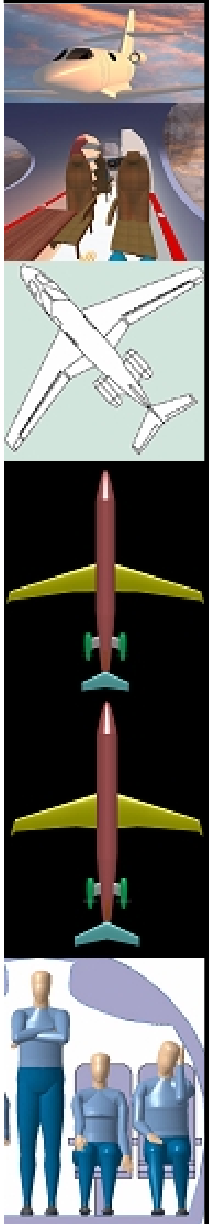
Joint Venture in Aircraft Design Education



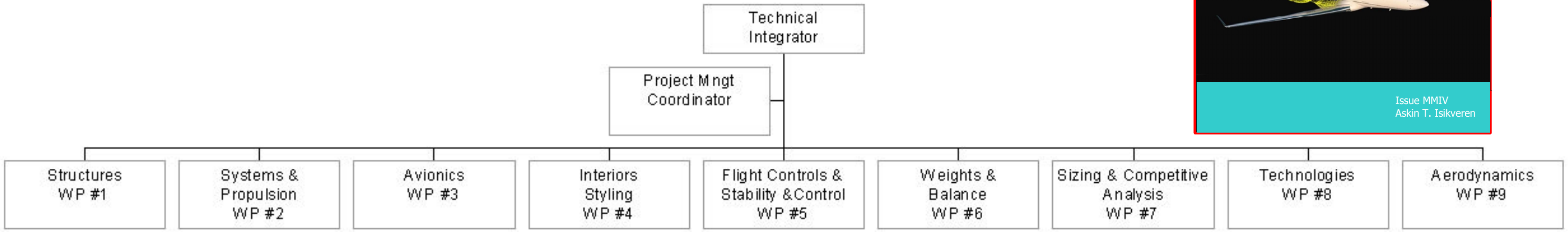
- Using the presented **model**, this joint venture for education has the following participants
  - Bombardier Aerospace (BA) in Canada, designated as “Industry”
  - Ecole Polytechnique de Montreal (EPdM) in Canada, designated as “Prime University”
  - The Royal Institute of Technology (KTH) in Sweden, designated as “Collaborating University”

- Multi-disciplinary design tasks for each educational partner strategically chosen according to their **respective competency**
  - EPdM for virtual product integration and systems integration
    - CATIA V5 for geometry construction
    - Close ties to Bombardier Aerospace, Chair in drag prediction & icing
  - KTH for specialised knowledge & internationally recognised numerical tools for aerodynamic design & refined S&C sizing
    - TORNADO & MSES
    - Close ties with SAAB & FOI on CFD dev/application, MIT on tools

EPdM AE4950 Aircraft Design Course

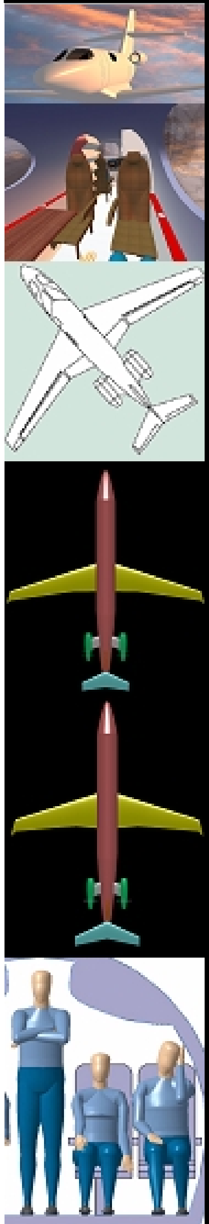


- 25 students organized into disciplinary groups to serve as “specialists” for a team project



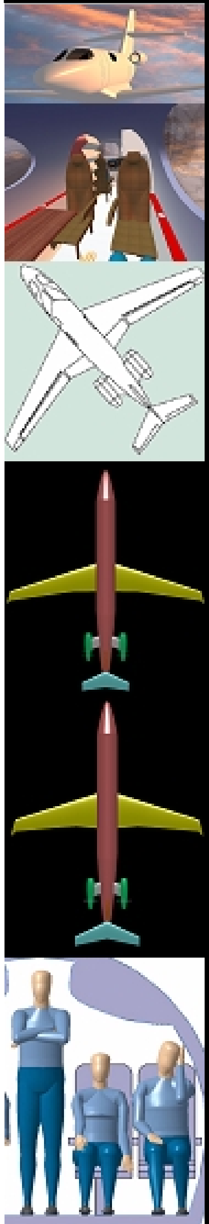
  - Allows opportunity to gain a greater insight into a specific technical discipline and comprehend the complex interactions
  - Foster skills on how to interact in a goal oriented technical team
  - Experience some of the challenges of managing the design of a high-value product
- Effective communication ensures project governance
  - Appointing a project management coordinator is key to success
  - Achieved via structured & frequent technical group meetings
  - Requirement for final review to senior academic staff & industry professionals fosters a high calibre of presentation skills

KTH 4E1222 Project Course in Aerospace



- Objective
  - Introduce students to industrial conceptual aircraft design through project work, to learn skills in the use of modern analysis & design tools
  - Central focus is to solve a real-world problems proposed by industrial clients in the form of a team-project assignment
    - Usually involves individual disciplines: aerodynamics, flight mechanics, aero-elasticity, structures, etc.
- Deployment – “gates” are used for purposes of governance, succession requires each to be approved by the supervisor
  - S1. Project definition, data collection and literature survey: What is known? New things needed?
  - S2. Defining a detailed specification of work and writing the contract of project deliverables
  - S3. Carrying out the contract. This includes computational analysis, sizing, optimisation, etc.
  - S4. Testing/checking of results: Project requirements fulfilled? Deliverables in hand?

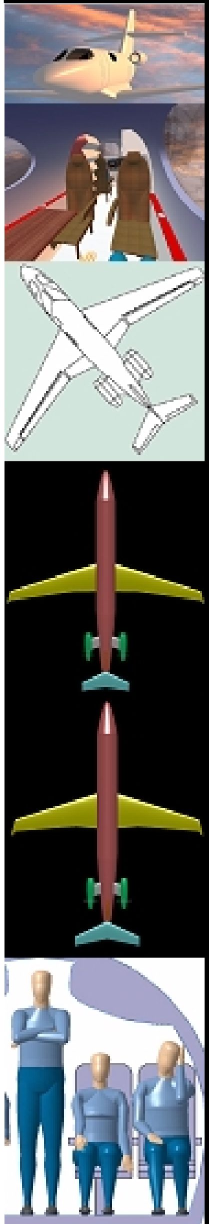
Y2004 RFP: Small Transport Aircraft Family



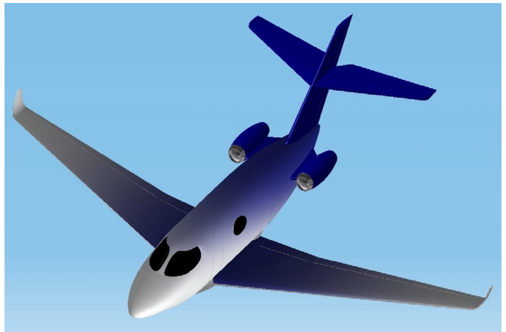
- RFP: Personal/micro-exec/air-taxi with another future offering aimed at the executive entry-level/very-light
  - Adaptable baseline
    - Personal – recreational, for enthusiasts, sporty interior
    - Micro-executive – dedicated business travel, productivity machine
    - Air-taxi – airports with infrequent/non-existent airline service
  - Baseline aircraft specs
    - First-time owners
    - 400-600 hours utilisation
    - To mitigate risk, optimal mix of contemporary technology required
    - Boston-Denver city pair
    - Superior performance
    - Very high reliability, low acquisition price & low operating cost

New Personal/Micro-exec/Air-taxi Aircraft	
Design PAX accommodation	Min. 5 (including pilot)
Cabin volume	At least 200 cu.ft
Weight per PAX	220 lb
Total baggage volume	At least 90 cu.ft (50 cu.ft pressurised)
Cabin requirements	Must accommodate lavatory and/or cabin galley/stowage
Design Range, IFR, 100 nm alt.	1550 nm @ M0.75
Normal cruise	At least M0.65
Maximum cruise	At least M0.75
Takeoff field length, ISA, s.l.	< 3000 ft
Takeoff field length, ISA+20°C, 5000 ft	< 5500 ft
Approach speed	< 100 KCAS
Initial cruise altitude	At least 37000 ft
Service ceiling	At least 41000 ft
Operational requirements	Accommodate 1+1 flight crew Certified for single pilot operations RVSM compliant

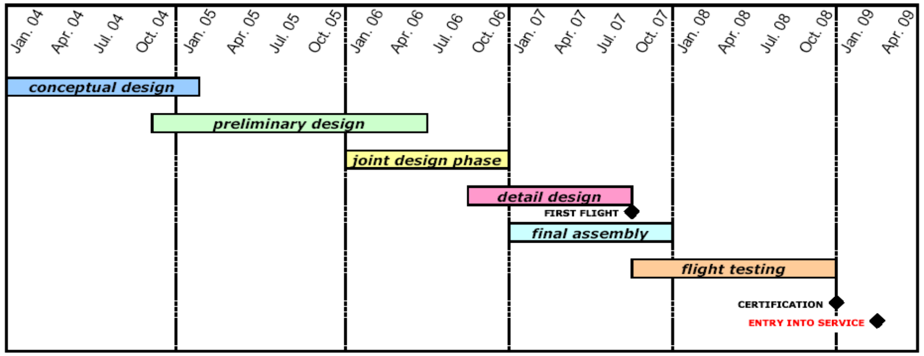
  - Family strategy to enter executive aircraft market segment



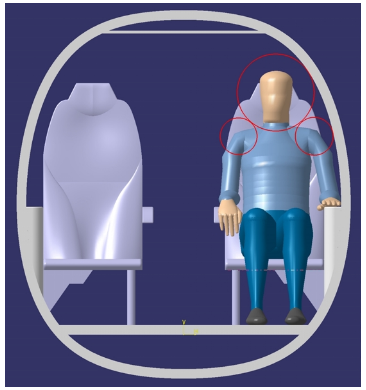
Y2004: EPdM “Blue Dolphin”

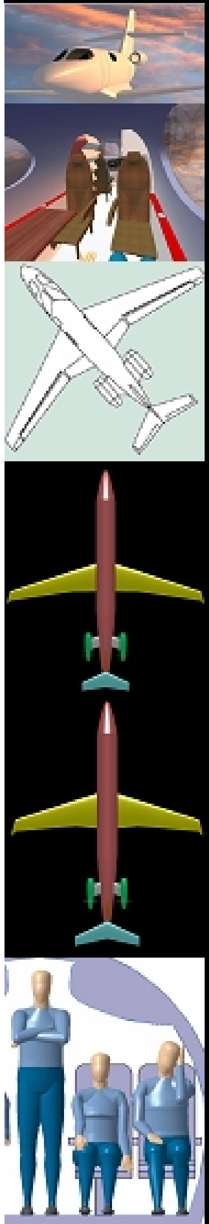


- Entry-into-service in 2Q09



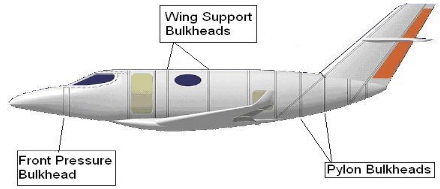
- Certification for single pilot operations
- Cabin Specifics
  - Standard layout 1 pilot + 5 PAX with lavatory
  - Special panoramic windows 762 x 406 mm, used as Type III emergency exits
- Avionics
  - Standard equipment tailored to assist novice pilots
- Flight Control System
  - Manual Primary FCS, Secondary FCS mechanically signalled with electro-mechanical actuation
  - No yaw-damper for dispatch reliability & low cost



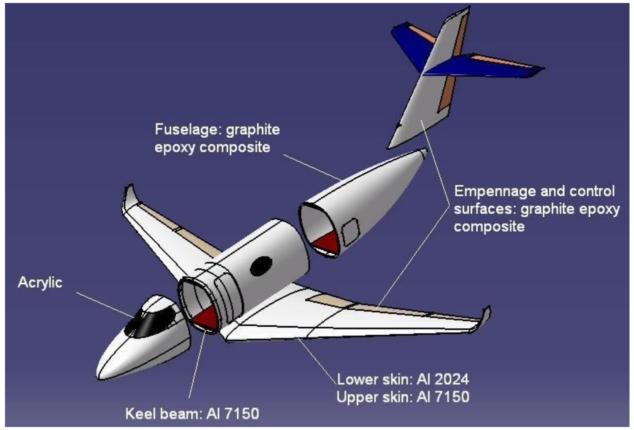


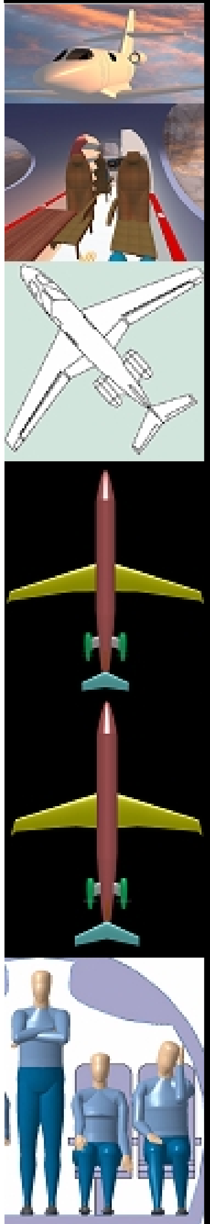
Structural Integration & Manufacturing Technology

- Fuselage
  - Three sections: nose, cabin & aft
  - Minimal bulkheads, 51 mm skin
  - Layer of visco-elastic material in order to improve the acoustic & thermal insulation



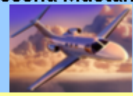
- Manufacturing Technology
  - Fuselage – filament winding
    - Not considered a high risk item due to industry familiarity
    - Simple and cheaper production
  - Nose, Empennage & Winglets – Structural Reaction Injection Moulding
    - Much faster than the Resin Transfer Moulding process
    - High productivity & flexible enough for many shapes
  - Wings & Flaps - Integrally machined
    - Suitable for high volume production, reduces bill-of-material
    - 10% lighter: lower fastener count & better load distribution



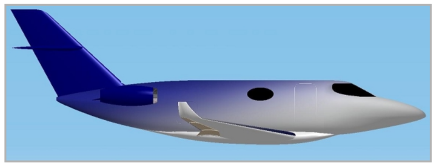


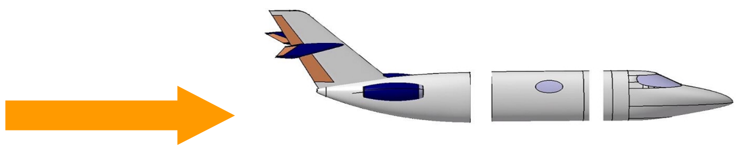
Competitors & Further Product Development

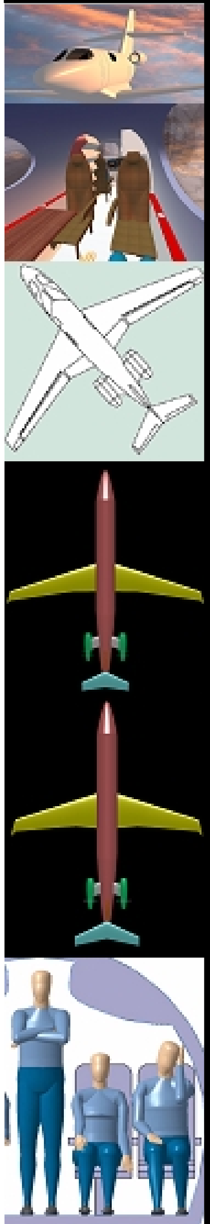
- Competitive Edge
  - Flies faster, travels a longer range, good field operations
  - Better than average cabin & baggage dimensions

Aircrafts for competitive analysis	AeroX Blue Dolphin 	Éclipse 500 	Cessna Mustang 	Safire Jet 	Avocet ProJet 
General caracteristics					
Published price ($)	**2 000 000**	950 000	2 295 000	1 395 000	2 000 000
Engine manufacturer	**Williams International**	Pratt & Whitney Canada	Pratt & Whitney Canada	Williams International	Pratt & Whitney Canada
Engine model	**FJ44-1A**	PW610F	PW615F	FJ33-4	PW615F
Number of engines	**2**	2	2	2	2
Thrust per engine (lb)	**1900 lb**	770 lb	1350 lb	1500 lb	1350 lb
Weights and loading					
Max T-O weight (lb)	**10600**	4700	N/A	6250	7160
Performances					
IFR range (nautical miles)	**1900**	1395	1300	1050	1200
Max Cruise Speed (Mach nb)	**0.75**	0.65	0.59	0.66	0.66
Long range cruise speed (Mach nb)	**0.65**	0.57	N/A	0.52	0.63
Takeoff distance (ft), sea level, ISA	**2305**	2155	3120	2500	3000
Max. altitude (ft)	**41000**	41000	41000	41000	41000
Cabin caracteristics					
Volume (cu. ft.)	**285**	191	250	235	259
Press. baggage volume (cu. ft.)	**50**	26	0	14	20
Unpress. baggage volume (cu. ft.)	**0**	0	45	0	28

- Family concept: micro-exec → very light executive transport
  - Minor derivative with fuse plugs fwd & aft of centre cabin

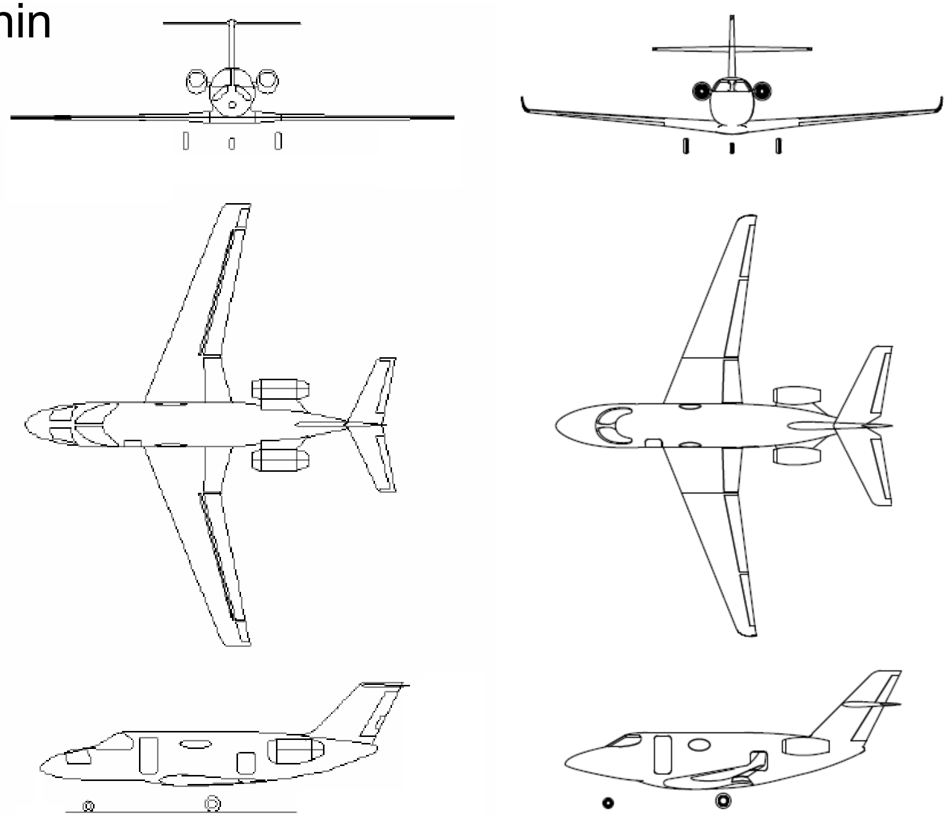






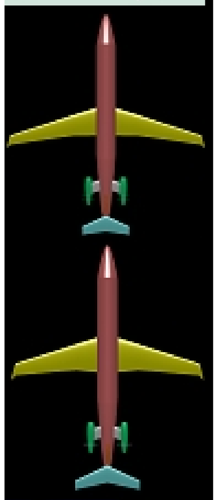
Y2004: KTH "Il Papero" (Competitor Proposal)

- Essentially a competitor proposal to the Blue Dolphin
  - Cross-section, interior layout, avionics, systems & equipment retained from Blue Dolphin
  - Freedom available in selecting an **alternative morphology** solution
    - Adoption of T-tail
    - Roll control with spoiler augmented by small ailerons
  - Work focused on examining novel aerodynamic solutions as well as refining aerodynamic attributes



Il Papero **Blue Dolphin**



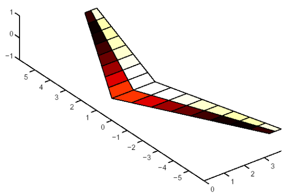
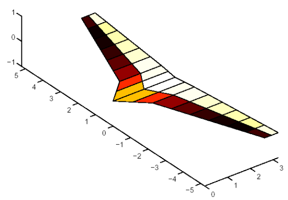

Investigation of Aerodynamic Improvements

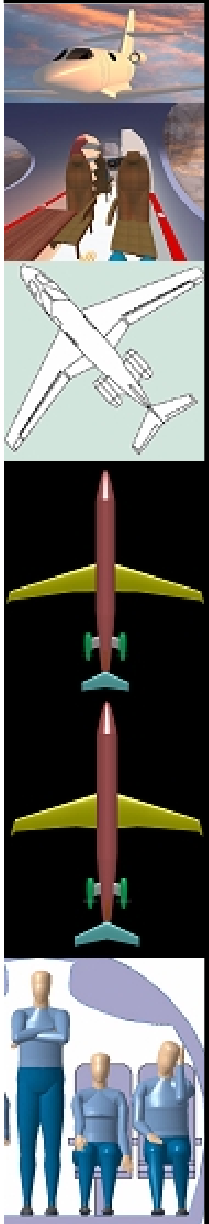
- Aerofoil selection and optimisation
  - Three candidates considered using **MSES** code (transonic design)
    - Sonic Roof-top
    - So-called Peaky
    - Super-critical

Family	Aerofoil	L/D Ratio	
		Mach 0.7	Mach 0.72
Sonic Rooftop	RAE6-9ck	43.01	42.37
‘Peaky’	RAE5214	46.6	46.6
Supercritical	$NACA_{(2)}0414$	38.18	31.35

Aerofoil L/D values

  - Final selection was **Peaky section**
    - Can reduce wing sweep
    - Can remove Fowler flap track fairings (at least 1% drag reduction)
    - Retains acceptable volumetric efficiency for fuel storage
- Wing glove study
  - Aim was to reduce wing loading, delay stall (increase C_{Lmax} for lower reference speeds) & improve fuel storage
  - Comparison with & without wing glove using TORNADO
    - A neutral performance result was found
    - Idea was dropped due to problems with landing gear integration, modest incremental fuel storage & ramp safety

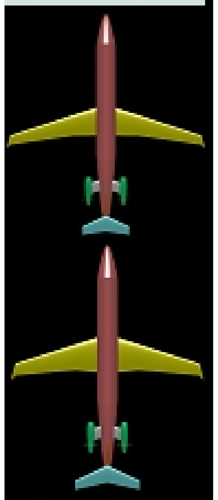


Y2005 RFP: Next Generation Regional Transport

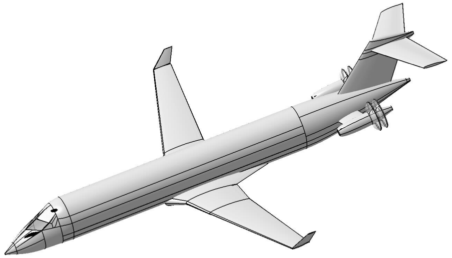
- RFP: 50-70 PAX family focused on turboprop renewal & organic growth into **turbofan** domain
  - Baseline aircraft specs
    - 70 PAX at 31” seat pitch
    - Limited-scale operations such as thin routes, actual PAX loads fluctuate
    - Combined exceptional field performance with high productivity
    - Must fly in and out of London City or Toronto City Center (steep approach)
    - Columbus-Denver city pair
    - Must operate autonomously
    - Emphasis placed on marketability (PAX prefer)
  - Family member – 50 PAX regional
  - Missionised aircraft for freighter, corporate & government/military

New Regional Transport	
Accommodation	70 PAX
Seat pitch	At least 31 in. (0.79 m)
Weight per PAX	225 lb (102 kg) includes baggage
Baggage volume	At least 7 cu.ft (0.20 m^3) per PAX
Overhead bin volume	At least 2 cu.ft (0.06 m^3) per PAX
Design Range, IFR, 100 nm alt.	1500 nm (2780 km) @ M0.70
Out-and-return maximum range	At least 800 nm (1485 km) @ M0.70
Number of 200 nm sectors without refueling	At least 4
Long Range Cruise	At least M0.65
Normal cruise	At least M0.70
Maximum cruise	At least M0.75
Takeoff field length, ISA, s.l.	< 4200 ft (< 1280 m)
Takeoff field length, ISA+30°C, 5000 ft	< 6500 ft (< 1980 m)
Approach speed	< 120 KCAS
Initial cruise altitude, ISA, MTOW @ takeoff	At least 31000 ft
Time-to-climb, ISA, MTOW @ takeoff	< 25 min.
Single Engine Net Ceiling, ISA, 95% MTOW	At least 17000 ft
Service ceiling	At least 35000 ft
Service Life	80000 cycles
Fatigue Life	200000 cycles
Operational requirements	High elevation airports Unpaved and contaminated runways Design intent for steep-approach 99.0% dispatch reliability and 99.5% scheduled completion rate @ EIS RVSM
Emissions	CAEP6 with 40% margin for NOX, CO, Hydrocarbons and Smoke
Noise	Average for cabin 76 dBA Stage 4 – 20 EPNdB
Operating Economics	Cash operating cost at least neutral with best comparable turboprop



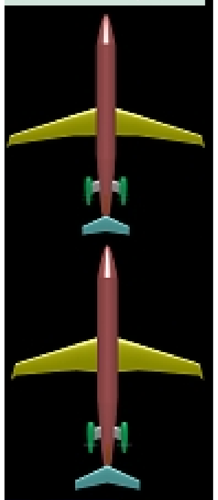




Y2005: EPdM "Horizon 1100"



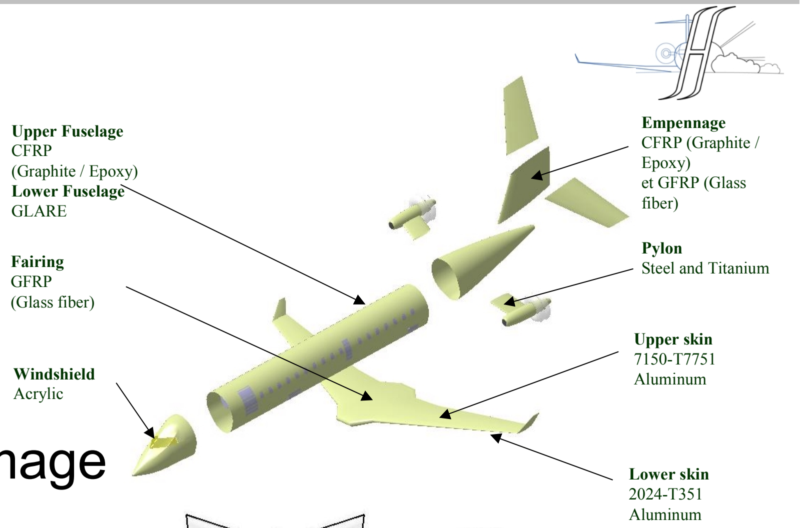
- Entry-into-service in 1Q10
- Propulsion - gearless counter-rotating open **rotor fan** rated at 10,000 lb.f each
- More Electric Aircraft
  - Hydraulic power free, Electro-mechanical (EMA) & Electro-hydrostatic (EHA) actuators
  - Lower maintenance & operating costs, no hydraulic fluid fire hazards, lower manufacturing times & bill-of-material
  - Landing gear: EHAs, electrically powered carbon brakes
  - Traditional pneumatic [engine bleed] system services cabin environmental control, ice & rain protection, engine start
- Flight Control System
  - Analog FBW with stability augmentation, 8% static margin
  - Primary FCS are EHAs, Secondary FCS use EMAs for spoilers & electric Power Drive Unit for high-lift & trim
  - Standard single yaw-damper – none required for dispatch

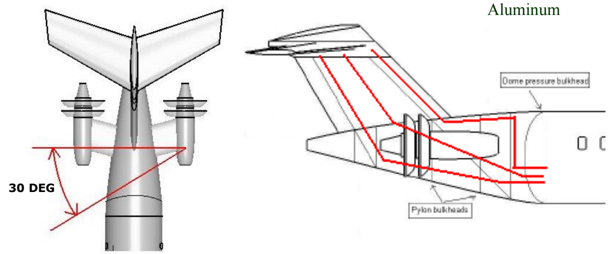



Power Plant, Structures & Operation

- Engine borne noise abatement
  - Target Stage 4 minus 10 EPNdB
    - Redesign fan blades using CFD methods & employ effective noise damping material
    - Inlet cowl to utilise new composite acoustical panels
- Rotor-burst & Foreign Object Damage
  - Titanium/composite fan blades
  - In case of fan blade separation designed to prevent catastrophic failure

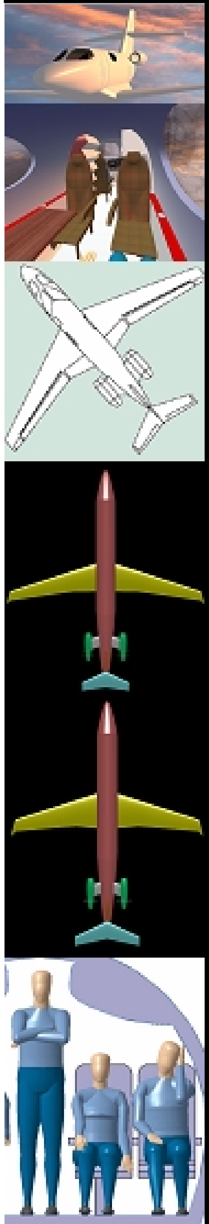




	Nom de la tâche	Durée
1	MAIN DECK	0,05 jour
2	Pos'n A/C / Stop Engines	1 min
3	Deplane Passengers	5 min
4	Cabin Cleaning	8,5 min
5	Galley Service	7 min
6	Emplane Passengers	6,5 min
7		
8	BAGGAGES HOLD	0,04 jour
9	Ready to Unload	1 min
10	Unload baggages	7 min
11	Load Baggages	9 min
12	Close up	1 min
13		
14	OTHER TASKS	0,03 jour
15	Refuel	10 min
16	Portable Water	6 min
17	Service Vacuum Toilets	8 min
18	Close Doors / Start Engines	1 min

- **20 minute turn-around**
- The aircraft is fully autonomous, no need for external stairs or Ground Power Unit

Competitors & Further Product Development



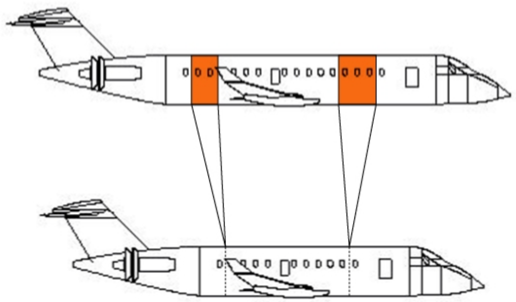
- **→** Competitive edge suited to turboprop renewal market
  - → Good comfort, climbs higher, flies faster, longer range, good field operations
  - → Community noise needs further work
  - → Excellent operating economics

Aerox HORIZON

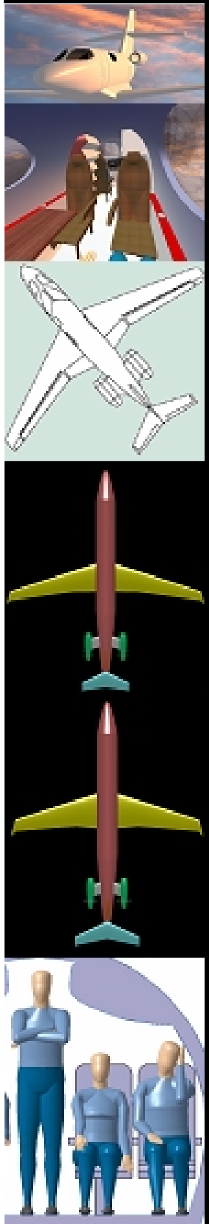
Competitor Comparison Chart

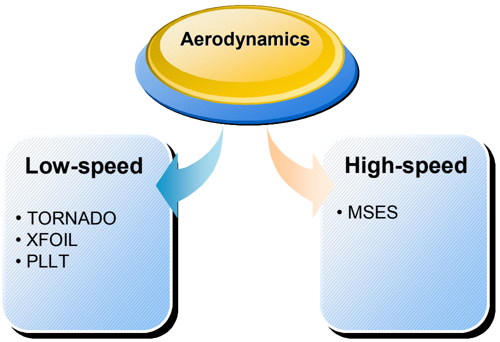
Design Criteria	Specifications	AEROX Horizon 1100	Bombardier Q400	Avions de Transport Regional ATR 72-500	Bombardier CRJ-700	Embraer ERJ-170
Purchase Cost	Acquisition Price (US$)	$23,300,000	$20,000,000	$17,500,000	$28,000,000	$25,310,000
Accommodation	Seating (standard)	70	74	68	70	70
	Weight per PAX (lb/PAX)	225	244	218	258	262
Cabin Dimensions	Seat pitch (in)	31	31	31	31	32
	Baggage volume/PAX (cu.ft)	7.31	10.23	7.14	7.8	7.3
	Overhead bin volume/PAX (cu.ft)	3.01	3.45	1.63	2.2	2.5
	Cabin Volume/PAX (cu.ft)	38.4	34.4	41.3	34.7	45.4
Propulsion	Engine Manufacturer	General Electric	Pratt&Whitney Canada	Pratt&Whitney Canada	General Electric	General Electric
	Engine Model	GE38 Propfan	PWC-150A turboshaft	PWC-127F turboshaft	CF34-8E5 turbofan	CF34-8C1 turbofan
	Number of Engines	2	2	2	2	2
	Rated Thrust/Shaft hp per eng, SL	9640lbT	5071 hp	2750hp	14200lbT	13790lbT
Cruise	Long Range Cruise (Mach)	0.65	0.47	0.41	0.78	0.75
	Normal cruise (Mach)	0.7	0.58	0.46	0.78	0.78
	Maximum cruise (Mach)	0.75	0.63	0.55	0.81	0.8
	Design Range, IFR, 100 nm alt. (nm)	1650	1353	714	1455	1675
Airfield Performance	Takeoff field length, ISA, s.l. (ft)	4166	4300	4015	5090	5135
	Approach speed (KCAS)	115	120	138	136	132
Cash Operating Cost	COC/Seat Mile - 200 nm (US$)	5.00¢	5.14¢	4.80¢	5.82¢	6.07¢
	COC/Seat Mile - 400 nm (US$)	3.50¢	4.00¢	3.71¢	4.20¢	4.40¢
	COC/Seat Mile - 800 nm (US$)	2.74¢	3.52¢	3.16¢	3.39¢	3.52¢
Noise	Noise Stage 3 Cum. Margin (EPNdB)	-20	-33	-31.3	-15.9	-21.2

- **→** Family concept
  - → 70 PAX → 50 PAX, derated engine
  - → Minor derivative with fuse plugs fwd & aft of centre cabin, retain part numbers
  - → Removal of 1 galley & 1 lavatory
  - → Similar handling characteristics
  - → No differential training for crew type rating



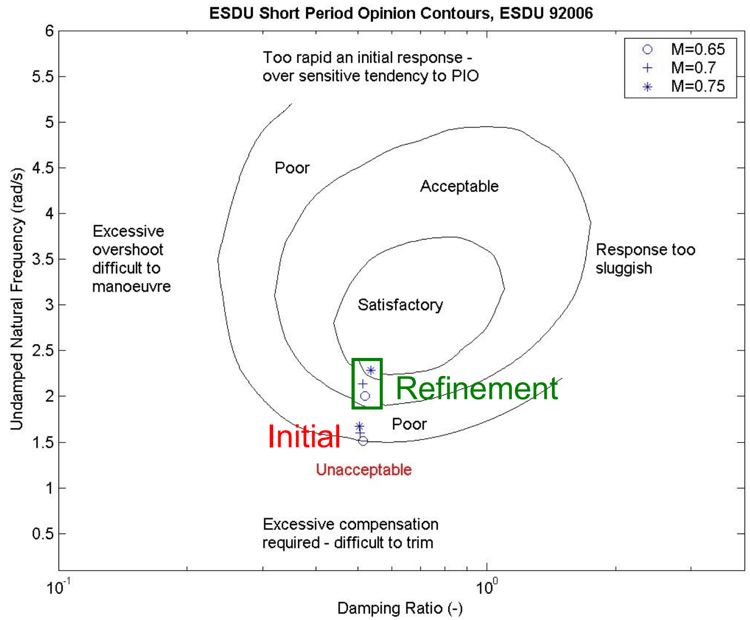
Y2005 KTH: Aero and S&C Refinement of "Horizon"



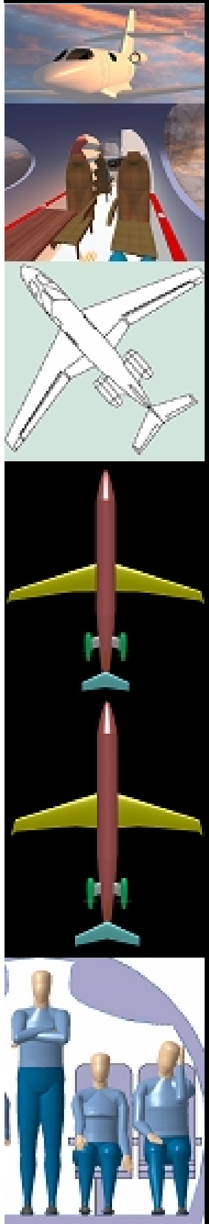


- ➔ Low and high-speed analysis/refinement
  - → Attempt to retain original low-speed targets
  - → Rule: $[M_{DD} - M_{crit} \geq 0.15]$ & $[M_{DD} > M_{MCRZ}]$
    - ↳ $\uparrow \Lambda_{Qchd}$
  - → Achieved satisfactory aerodynamic performance of the wing, however, steep approach still was left unresolved

- ➔ Refined sizing for S&C: Short Period & Dutch-Roll required remedying
  - → Wing
    - ↳ Moved fwd, $\uparrow S_W$, $\downarrow$ AR, $\downarrow \Gamma$
  - → Horizontal tail
    - ↳ Lowered, $\uparrow S_{HT}$, $\uparrow AR_{HT}$
  - → Vertical tail
    - ↳ $\downarrow S_{VT}$ (due to wing movement)



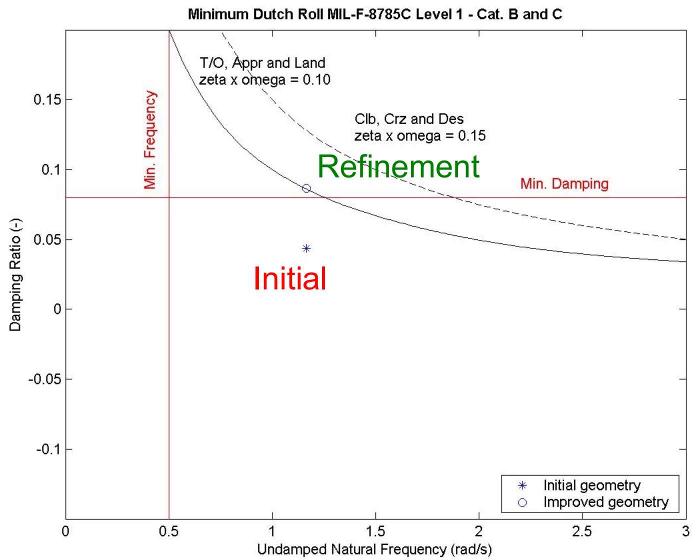
"Horizon 1100" S&C Improvements: Further Details

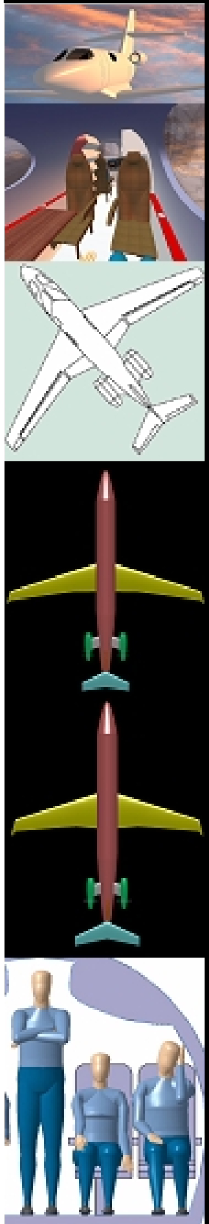


- Aerodynamic derivatives
  - New configuration has better drag properties & more benign $C_{M\alpha}$
  - Improvements were considered to be a suitable trade against some loss of lift
- No significant change in moments of inertia resulted

	$C_{L\alpha}$ (1/deg)	$C_{D\alpha}$ (1/deg)	$C_{m\alpha}$ (1/deg)
Initial Geometry	0.0952	0.0026	-0.5891
Improved Geometry	0.0924	0.0018	-0.4698

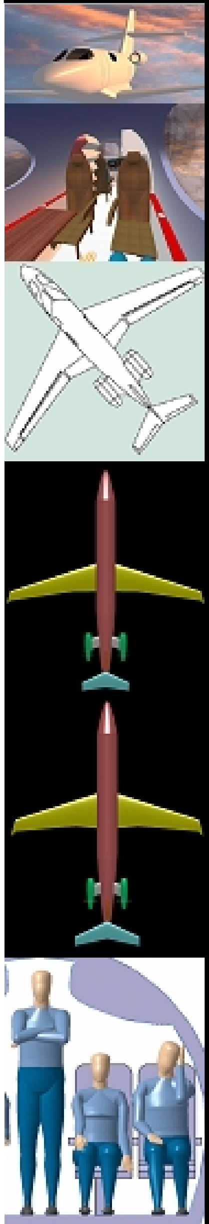
Type of motion	Name	Period (s)		Time-to-half (s)		Cycles-to-half (-)	
		Initial	Imprd	Initial	Imprd	Initial	Imprd
Longitudinal	Phugoid	$1.76e^{5}$	$1.81e^{6}$	94.98	95.9	$5.4e^{-4}$	$5.3e^{-4}$
	Short-period	4.35	2.92	0.82	0.58	0.19	0.20
Lateral	Dutch roll	5.11	5.40	12.94	6.84	2.52	1.26
	Spiral	128.4	117.5				
	Rolling Convergence	0.86	0.89				



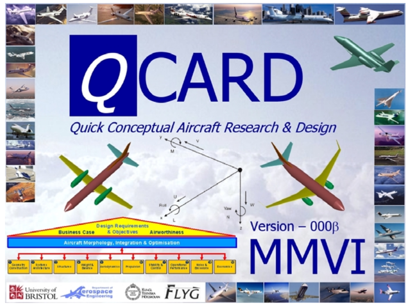


Conclude: Lessons Learned & Cascading Benefits

- Industry-university & university-university relationships are fostered, subsequently strengthened
- **Three groups** of beneficiaries
  - Industry
    - Offered graduates who have systems integration experience
  - Educational institutions EPdM & KTH *directly*
    - Improved quality of education, marketable graduates
  - Other educational institutions *indirectly*
    - Ever-increasing numbers of international students
    - Institutions: University of Bristol, University of Edinburgh, ENSTA & Politecnico di Milano

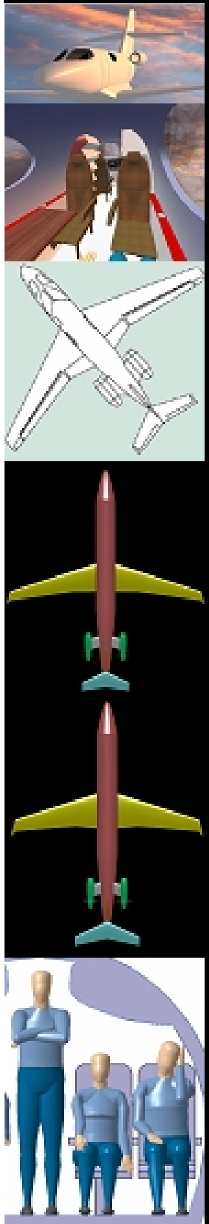


Motivations for Continual Improvement



- Additional industry-university opportunities
  - New research possibilities
    - Inter-university final year project/thesis activities, e.g. 2005-06 UoB-KTH **QCARD software development**
  - New initiatives
    - **Industry internship**/research programmes, e.g. Boltjes' "Optimisation of a Three Lifting Surface Configuration for a Business Aircraft" (BA-KTH)
    - Assisted to generate previously non-existent third party industry-university ties

- Educational Initiatives
  - KTH developing **new unit** in curriculum: 1233FRT Design Course
    - Aim is to set up a foundation between course work and subsequent final year "exjobb" thesis project; carry out an industry-defined project
    - Students fostered to be self-sufficient, e.g. must find own information
    - Project topics: aerodynamics – flight mechanics – aero-elasticity
    - Learn project work: process to reach a desired objective
    - Learn teamwork: organisation & management dynamics



Future: Collaborative Design Education Activities

- New collaborative education set up between **UoB & KTH**
  - 2005-06 **UoB-Airbus UK** ultra long haul wide-body design project
    - B747 replacement; Middle-East to US operations

↳ Passenger Capacity	- 360 Seats (2-class)
↳ Range	- 7300 nm
↳ Take-Off Distance @ MTOW	- < 3350 m (ISA + 15°C, Sea Level)
↳ Approach speed	- < 150 kts CAS
↳ Engine-out Ceiling	- 16000 ft at 97% MTOW, ISA + 10 °C
↳ Climb Time	- 25 min. to 35000 ft
↳ Other Constraints	- Emergency exits to cover high density layout (30” seat pitch)
↳ Airport Compatibility	- ICAO Category F (span & length < 80m)
↳ Turn Around Time	- < 90 min.
↳ Noise and Pollution	- Meet Stage 3 minus 25 EPNdB noise limit
	- LHR QC0.5 Approach, QC1 take-off
↳ Operating Costs	- 15% improvement relative to B777-300ER
↳ Family concept	- Low Gross Weight option (range 4500nm)
	- 15% PAX growth (with 6500nm range)