1998/1999 AIAA Foundation Graduate Team Aircraft Design Competition:

Super STOL Carrier On-board Delivery Aircraft

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Outline

• Design Requirements & Design Philosophy
• Preliminary Weight & Performance Sizing
• Configuration Selection & Component Design
• Propulsion Selection & Installation
• Structural Layout
• Drag Estimation
• Performance Analysis
• Cost Estimation
• Design Optimization
• Conclusions
Design Requirements

- Super Short Takeoff and Landing (SSTOL) aircraft to provide center-city to center-city travel using river “barges”
- Also fulfill needs of US Navy to replace the C-2 Greyhound for Carrier On-Board Delivery (COD)
Design Requirements (cont.)

- Takeoff ground roll of **300 ft**, landing ground roll of **400 ft**
- 1500 nm cruise at 350 knots
- Payload of 24 passengers and baggage for commercial version
- Payload of 10,000 lb, capable of carrying two GE F110 engines for the F-14D, and a spot factor of 60 ft by 29 ft for military version
- **Arresting hooks or catapult devices not allowed!**
- Technology availability date is 2005
Design Philosophy

- Investigated two design approaches: tilt-wing and fixed-wing with upper surface blowing (USB) flaps
- Tilt-wing (as opposed to tilt-rotor) concept demonstrated by Canadair CL-84 and XC-124
- USB flaps utilized on NASA Quiet Short-haul Research Aircraft (QSRA) and Boeing YC-14
Preliminary Weight & Performance

• Used to estimate weight, wing area, and thrust or power to meet performance constraints (cruise speed and range, takeoff and landing ground rolls)

• Fixed-wing with USB flaps:
  – 48,635 lb takeoff weight
  – 1000 sq ft wing area
  – 30,000 lb installed thrust

• Tilt-wing:
  – 59,922 lb
  – 700 sq ft wing area
  – 10,500 installed horsepower
Fuselage

- Fuselage laid out around engine containers:
  
  Total of 4 containers for the 2 GE F110 Engines
Fuselage (cont.)

Military Version with two GE F110 engines for F-14D

Passenger version with accommodation for 24 passengers
Wing

- Highly constrained by spot factor requirement (60 ft x 29 ft, wing folding allowed)
- Final design incorporated wing pivoting and folding
Propulsion & High Lift

- Two different concepts for high lift:
  
  (I) Airflow over wing without BLC
  (II) USB Concept
  (III) BLC used to delay boundary layer build-up

Upper Surface Blowing (USB) Flaps

Tilt-wing
Propulsion & High Lift (cont.)

- Analyzed using methodology in *Aerodynamics of V/STOL Flight* by McCormick
- Flight test and wind tunnel data for ‘sanity’ check

![Graph showing variation of lift coefficient](image)

**Sample Variation of Lift Coefficient**

\[
\delta_f = 10 \text{ deg} \\
\alpha_f = 0 \text{ deg} \\
C_{\mu} = \frac{\text{Thrust}}{q_{\text{bar}} S_{\text{ref}}}
\]
Structural Layout

- Based on ‘typical’ configurations of cargo aircraft and consists of frames, longerons, ribs, and spars
- Efforts to make use of advanced materials where useful and cost effective
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Wing Structure
Empennage Structure
Drag Estimation

- Drag build-up approach: drag of each major component computed, plus interference effects
- Induced drag computed as function of wing/body lift coefficient

![Drag Polar and L/D vs. CL for M = 0.61](image)
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Performance Analysis

- Equations of motion numerically integrated to compute takeoff and landing ground roll
- Climb rate calculated from engine data & drag polar

Takeoff and Landing Ground Rolls

AEO Climb Rate

Graphs depicting takeoff and landing ground roll as a function of weight, and AEO climb rate as a function of Mach number.
Performance (cont.)

- Specific range computed from drag polar and engine data for various weights
- Range calculated by integrating specific range, taking into account reserves requirements

![Graph showing Specific Range and Payload-Range](image)

**Specific Range**
- Valid for h = 37,000 ft

**Payload-Range**
- Design Payload
- Ferry Range
Cost Estimation

- Cost estimation method based on statistical data gathered for many existing aircraft
- Research, Development, Test, and Engineering (RDTE), Acquisition, Operating, and Disposal costs were computed, leading to the Life Cycle Cost (LCC)

Military Version Operating Costs: 8.44US$/nm
Commercial Version Operating Costs: 8.16US$/nm
Block Distance: 1500 nm

Operating Cost Breakdown

- Flying: 27%
- Maintenance: 17%
- Depreciation: 6%
- Landing Fees/Nav./Taxes: < 1%
- Financing: 24%
- Indirect: 26%

Military Version Life Cycle Cost: $155B (750 military airplanes)
Commercial Version Life Cycle Cost: $149B (750 commercial airplanes)
Design Optimization

• Various subsystem analyses (high lift, weight, propulsion, performance, cost, etc.) were combined into a collaborative optimization code

• The goal of the optimization was to produce the best design (in this case as measured by life cycle cost) which met all of the design requirements – takeoff and landing ground roll, cruise speed and range

• Constraints for FAR / MIL certification such as stability, climb gradients, tipover, etc. were also applied
Design Optimization (cont.)

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Design Optimization (cont.)

- A final design was selected based on the relative costs of the various designs:

Cost Comparison

<table>
<thead>
<tr>
<th></th>
<th>Vertical Takeoff Tiltwing</th>
<th>Short Takeoff Tiltwing</th>
<th>Short Takeoff Fixed Wing</th>
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<tr>
<td>DOC</td>
<td>$9.06/nm</td>
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<td>Fuel Price</td>
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<tr>
<td>LCC</td>
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</tbody>
</table>

Final Three-View
Trade Study on Performance Requirements

- Although performance requirements were specified, constraints were varied to analyze effect on LCC
- One of the more interesting is that for takeoff ground roll:

![Variation of Life Cycle Cost with Takeoff Ground Roll Constraint](image)
Conclusions

• Upper Surface Blowing (USB) flaps and tilt-wing considered as means to achieve Super Short Takeoff and Landing (SSTOL)

• Subsystem analyses methods developed for use in collaborative optimization

• A fixed-wing design with USB flaps was selected for its lower Life Cycle Cost

• Design studies showed that a relaxed takeoff constraint would have a significant effect on Life Cycle Cost