CAL POLY, San Luis Obispo

Presents

LOW COST COMMERCIAL TRANSPORT DESIGN

to:
NASA/USRA
Universities Advanced Design Program
10th Annual Summer Conference
Pasadena, CA

June 15, 1994
CAL POLY DESIGN CLASS

- Year Long Design Class
- 38 Senior Aero Engineering Students
- 5 Design Teams
**RFP OVERVIEW**

- **M > 0.7 @ Best range Velocity**
- **Range: 3,000 n.mi.**

CAL POLY, San Luis Obispo
PRESENTATION OUTLINE

- **ROMAN FRY**
  - PLAN-IT X
  - FOWL ENTERPRISES
  - CENTRAL COAST DESIGNS

- **GREGORY KING**
  - NON-SOLO

- **MIKE LUJAN**
  - FLYING CIRCUS

- **ROMAN FRY**
  - Concluding Remarks
PLAN-IT X  OFP-6M

- **TWIN AISLE**
  - Fineness Ratio 6.3
  - Small C.G. Excursion
  - Large Cross Sectional Area
  - Optimal Total Volume/Total Wetted Area
  - 12 LD-3 Containers

- **Engines**
  - High Bypass Ratio Advanced Ducted Prop
  - Improved SFC

- **Aerodynamics**
  - Near Midwing, Shark Fins, Small Tail Size
DOC BREAKDOWN

Maintenance 33%
Operations 31%
Depreciation 27%
Finance 7%
Landing 2%

ACQUISITION COST = $ 29.5 M
Regional Airport Market
- Cross Country Routes
- Hub & Spokes Relief

Aerodynamics
- HLFC
  - 10% Drag Reduction
  - L/D = 21.5
  - Mission Accomplished with System Failure
  - Not Fuel Price Sensitive

Low Cost
DOC BREAKDOWN

Acquisition Cost = $29 M

- Maintenance: 37%
- Operations: 28%
- Depreciation: 27%
- Finance: 7%
- Landing Fees: 1%
CENTRAL COAST DESIGN  8-BALL EXPRESS

- Conventional Design
  - Lower Maintenance
  - Reduced DOC
  - Lower Acquisition Cost
  - Customer Appeal

- Concurrent Engineering
  - Ease of Design, Manufacturing, Production
  - Lower Production Cost

- Cargo Capacity
  - 8000 lbs
  - Extra Revenue Source
DOC Breakdown

- Depreciation: 27%
- Maintenance: 30%
- Flight: 34%
- Landing Fees: 2%
- Finance: 7%

ACQUISITION COST = $28 M
THE ALUMINUM FALCON

- Innovative M-Wing Design
- Fly-by-Wire Flight Control System
- Judicious Use of New Materials
- Powerful High Lift System
- Low Cost
AF-1 DESIGN POINT

- $W_{to} = 140,000$ lbs
- Takeoff $W/S = 131$ psf
- Wing Planform Area = 1069 sq ft
- Takeoff $T/W = 0.32$
- Required Total Thrust = 46,000 lbs
- Takeoff $C_{L_{max}} = 2.3$
- Landing $C_{L_{max}} = 3.1$
THE ALUMINUM FALCON

AF-1

Aspect Ratio = 10
Wing Sweep = 27 deg
Dihedral = 3 deg

103’ 132’ 31’

12’10” 31’

103’ 132’

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THE M-WING CONCEPT

- Researched During the Second World War
- Offers Many Advantages of an Unswept Wing
- Advanced But Feasible
CG SHIFT COMPARISON

M-Wing
CG Shift
~10%MAC

Aft Swept Wing
CG Shift
~20%MAC
CG SHIFT COMPARISON

- Standard Wing
- M-Wing

Weight (lbs)

MAC

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TORQUE COMPARISON

Dr. John Doe

AF-1 Sweep Angle

Aft-Swept Wing

M-Wing

Torque (ft-lbs)

Wing Sweep (Degrees)
AF-1 FORWARD AC LOCATION

Fwd CG

AC

Aft CG
AF-1 LANDING GEAR LAYOUT

- Wing Trailing Edge
- Fuselage Skin
- Actuators
- Rear Spar
- Fuselage Centerline
  - <Tail
  - Nose>
AF-1 LANDING GEAR

DOUBLE BOGIE VS. TWIN

ADVANTAGES

- Extended Tire / Brake Life
- All Ten Tires the Same Size
- Extended Maintenance Interval
- No Fairing Required - Lower Fuel Cost
- Lower LCN

DISADVANTAGES

- Reduced Braking Effectiveness on Rear Tires
- Increased Production Cost
**M-WING VS AFT-SWEPT WING**

**ADVANTAGES**
- Reduced CG Travel
- Reduced Torque on Center Wing Box
- AC Located Further Forward
- No Yahudi or Fairing for Landing Gear
- Increased Inboard Lift Capability

**DISADVANTAGES**
- Increased Wing Weight
- Wave Drag Penalty
AF-1 LONGITUDINAL X-PLT

Ksm = -5%

Sh = 210 sq ft

Xcg

Xac

Horizontal Tail Area (sq ft)

0 200 400 600 800

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AF-1 DIRECTIONAL X- PLOT

V. Tail Area (Sq. Ft.)

Sv = 200 ft²

V. Tail Area (Sq. Ft.)
AF-1 FLIGHT CONTROL SYSTEM

- Three Axis Electronic Fly-by-Wire
- Triple Redundancy
- Stability Augmentation in Pitch Axis
COMPOSITE MATERIALS

- Weight Savings
- Fewer Parts - Assembly & Production Savings
- Greater Standardization
AF-1 MATERIALS SELECTION

- Spar Chords
- Spoilers
- Radome
- Landing Gear Doors
- Nacelle Cowl
- Flap Track Fairings
- Fin Leading Edge
- Fixed Trailing Edge Panels
- Rudder
- Tailplane & Elevator
- Seal Plates
- Wing to Body Fairing
- Flaps
- Ailerons
- Bottom Access Panels

Materials:
- Hybrid Composites
- GFRP
- Improved Al Alloy
- CFRP
AF-1 HIGH LIFT SYSTEM

- Takeoff Maximum Lift Coefficient = 2.3
- Landing Maximum Lift Coefficient = 3.1
- Full Span Double Slotted Fowler Flap
- Full Span Variable Camber Krueger Flap
AF-1 HIGH LIFT SYSTEM

Full Span Variable Camber Krueger Flaps

Front Spar

Rear Spar

Double Slotted Fowler Flaps
VARIABLE CAMBER KRUEGER FLAPS

RETRACTED
- Space for Systems
- Space for Anti-Icing
- Front Spar
- Support Structure
- Rotary Actuator
- Drive Arm

EXTENDED
# AF-1 Performance

<table>
<thead>
<tr>
<th></th>
<th>B737-400</th>
<th>MD-83</th>
<th>A320-200</th>
<th>AF-1</th>
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<tbody>
<tr>
<td>W/S</td>
<td>127</td>
<td>126</td>
<td>125</td>
<td>131</td>
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<tr>
<td>Takeoff Field Length (ft)</td>
<td>8,200</td>
<td>8,375</td>
<td>7,680</td>
<td>6,960</td>
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<tr>
<td>Landing Field Length (ft)</td>
<td>6,070</td>
<td>5,200</td>
<td>5,040</td>
<td>4,940</td>
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<tr>
<td>Cruise M</td>
<td>0.73</td>
<td>0.76</td>
<td>0.80</td>
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AF-1 INTERIOR CONFIGURATION

154 PASSENGERS
THREE-CLASS
42/36/32 IN PITCH

178 PASSENGERS
ALL-ECONOMY
32 IN PITCH
AF-1 ADVANTAGE:

LOW COST
M-WING RISK ASSESSMENT

- M-Wing Risk: $128.8 Million
- Low Risk

Current engine

Aluminum with standard composites

Fly-by-wire available
### AF-1 Production Cost

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Engines and Avionics Cost</td>
<td>16 million</td>
</tr>
<tr>
<td>Interiors Cost</td>
<td>0.3 million</td>
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<tr>
<td>Manufacturing Materials Cost</td>
<td>1.6 million</td>
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<tr>
<td>Manufacturing Labor Cost</td>
<td>3.3 million</td>
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<tr>
<td>Tooling Cost</td>
<td>0.3 million</td>
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<tr>
<td>Quality Control Cost</td>
<td>0.4 million</td>
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<tr>
<td><strong>Total Production Cost</strong></td>
<td><strong>22 million</strong></td>
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1994 US $ per aircraft
AF-1 ADVANTAGE:

1994 US $

AIRPLANE ESTIMATED PRICE

$28 million
AIRPLANE PRICE COMPARISON

Airplane Price ($/avail. seat)

- AF-1
- MD-95
- MD-90
- Boeing 737-400
- A320-200

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AF-1 DOC BREAKDOWN

- Flying: 37%
- Depreciation: 31%
- Maintenance: 24%
- Financing: 7%
- Fees: 1%
AF-1 DIRECT OPERATING COSTS

1994 US $

$5.28 per nmi

3.25 cents/ASM
FLYING CIRCUS

FC-1D
The FC-1D

Max. Takeoff Weight: 135,200 lbs
Wing Area: 1150 Sq. ft.
Aspect Ratio: 10
Fuselage Diameter: 12.9 ft.
c/4 Sweep: 23.9°
Main Wing Dihedral: 6°

123.3 ft.

126.7 ft.
FC-1D Design Parameters

- MTOW = 135,200
- Wing Loading = 117 psf
- Wing Area = 1150 sq. ft.
- T/W = 0.37
- $C_{L_{\text{MAX LANDING}}} = 3.0$
- $C_{L_{\text{MAX TO}}} = 2.4$
- Cruise Mach = 0.8
- Cruise Altitude = 39,000 ft
Payload Range Diagram

179 PAX
153 PAX
Structural limit
Fuel Capacity
153 Passengers
1st Class Seat Pitch 40 in.
Economy Class Seat Pitch 32 in.

179 Passengers
Economy Class Seat Pitch 29 in.
Baseline Aircraft

- Used as a Benchmark
  - A Model of Existing Aircraft

Aircraft Specifications

- RFP Performance Compliance
- Conventional Design
- All Aluminum
- DOC Modeled Using Industry Data
Baseline vs. Industry DOC

Baseline

Industry Average

DOC (1994 U.S. Dollars/numj)
Technological Risk Assessment

Target Improvement Areas
- Aerodynamics
- Propulsions
- Materials

Technology Selection Criteria
- Near Term Technology (year 2000)
- Existing in Prototype or Experimental Form
- Wind Tunnel Tested
Aft Wing Nacelle, Riblets, and Spiroid Implementation
Advantages:
- Clean Flow Over Upper Wing
- More Favorable Cross-sectional Area distribution
  - Lower Wave Drag
  - Higher Drag-Divergence Mach Number
- Enhanced Wing Lift

Disadvantage:
- Increased Tendency To Flutter
FC-1D Flutter Solutions

- Determine Critical Flutter Conditions Through Extensive Testing and Analysis
- Suppress Flutter to $V_D$
  - Stiffen Wing
- Implement Active Flutter Control System at Speeds Greater than $V_D$
  - Existing or Auxiliary Control Surfaces
  - Must Demonstrate High Reliability
Pylon Structural Arrangement

- Dry Bay
- Aux. Spar
- Rear Spar
- Engine Pylon Torque Box
- Torque Link
- Integrated Torque Box
FC-1D Thrust Reversers
Riblets

Advantages
• Minimizes Skin Friction Drag
• Reduces Total Drag by 4%

Disadvantages
• Questions Remain About Durability
• Sensitivity to Ultraviolet Radiation
Spiroids

- Reduce Total Drag by 2.0%
  - 1.7% Reduction in Fuel Burn

- Reduced Vorticity Levels
  - Decreased Separation Distance

- Enhanced Plane Stability
Drag Reduction Benefits Relative to a Planar Wing

Courtesy Aviation Partners, Inc.

% Change in Wing Span

% Change in Drag

Spiroid

Blended Winglet

Conventional Winglet

CAL POLY, San Luis Obispo
Effect of Advanced Technology On DOC

% Change in Drag

% Change in DOC

-5.00% -4.00% -3.00% -2.00% -1.00% 0.00% 1.00%

-5.00% -4.00% -3.00% -2.00% -1.00% 0.00% 1.00%

Aft Nacelle

Riblets

Baseline

Spiroids
FC-1D Normalized to Baseline aircraft
FC-1D vs. Baseline and Industry Averages

- Industry Average
- Baseline aircraft
- FC-1D

U.S. Dollar per nmi
Life Cycle Cost Breakdown

- **Operating**: 69%
- **RDTE**: 25%
- **Acquisition**: 5%
- **Disposal**: 1%

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DOC Breakdown of the FC-1D

- Financing: 7%
- Crew Cost: 21%
- Fuel & Oil cost: 27%
- Maintenance Burden: 10%
- Depreciation: 18%
- Engine Maintenance: 9%
- Airframe: 3%
- Landing and Taxes: 3%
- Insurance: 3%
DOC vs Competitors on a 3000 nmi trip
Conclusion

• Plan-It X
• Fowl Enterprises
• Central Coast Designs
• Non-Solo
• Flying Circus
AIAA/ Lockheed Undergraduate Design Competition

RFP Compliance

- Passenger Capacity: Mixed Class, 153
- Front and Rear Galleys
- Takeoff within FAA Field Length of 7000 ft
- Climb at Best Rate to Best Cruise
- Cruise at 0.99 $V_{br}$
- Land with Domestic Reserves within FAA Field Length of 5000 ft
- Meets FAR Part 36, Stage III Noise Regulations
- Conforms to FAR for this Type of Aircraft

- Low Cost Commercial Transport
Recommendation

Highest Savings in US$/LB THRUST
CAL POLY, San Luis Obispo

Low Cost Commercial Transport

M > 0.7 @ Best range Velocity
Range: 3,000 n.mi.

CAL POLY

New York