HALE UAV: AeroVironment Pathfinder

Aerodynamic and Stability Analysis

Case Study: Planform Optimization

Desta Alemayehu
Elizabeth Eaton
Imraan Faruque

Photo courtesy NASA Dryden Photo Gallery
Pathfinder History

- Designed and fabricated by AeroVironment in 1981
- Determined technology insufficient to support multi-day duration flights under solar power and Pathfinder was put into storage
- In 1993, brought back to flight by Ballistic Missile Defense Organization
- Transferred to NASA in 1994 to support Environmental Research Aircraft and Sensor Technology (ERAST) program
- ERAST program demonstrated that a high AR, solar-powered lightweight craft could take off and land at an airport and fly at extremely high altitudes (50-80K ft)
- ERAST also determines feasibility of such UAVs for carrying instruments used in scientific studies

Photo courtesy NASA Dryden Photo Gallery
ERAST Milestones

- Sept. 11, 1995: Sets first altitude record for solar-powered aircraft at 50,000 ft during 12-hour flight
- October 21, 1995: Damaged in hangar mishap
- July 7, 1997: Sets new altitude record for solar-powered and propeller-driven aircraft at 71,530 ft
- Modified into the longer-winged Pathfinder Plus, still used for tests at NASA DFRC
- Aug. 6, 1998: Pathfinder Plus breaks old record with flight at altitude of 80,201 ft
- Aug. 13, 2001: Helios sets record at 96,863 ft in near 17-hour flight
- June 26, 2003: Helios lost in flight mishap near Kauai, Hawaii

Photo courtesy NASA Dryden Photo Gallery
Pathfinder Configuration

Span: 99 ft
Chord: 8 ft
Wing Area: 792 ft²
AR: 12.375
Elevator Chord: 0.89 ft

# Elevators: 26 (full span)

\[ x_{cg} : 0.5 \text{ in fwd LE} \]

Center Panel: 22.1 ft span and 0° dihedral
Mid Panel: 18.9 ft span (each) and 3° dihedral
Tip Panel: 18.8 ft span (each) and 6.5° dihedral

Three-View Drawing courtesy AeroVironment, Inc.
Specs and Performance

- W=550 lbs (includes 50 lbs payload)
  - W/S=0.694 psf
- Solar array covers 75% of upper surface and can generate near 8000 W at solar noon
- Six gearless 1.5 hp electric motors consisting of fixed-pitched, 2-bladed 79-inch diameter props, brushless DC motor, nacelle, cooling fins, and composite mounting strut
  - T/W=0.10 at 60,000 ft, P/W = 13.6 W/lb
- Composed of carbon composite spar, lightweight composite ribs and transparent plastic wing skin
  - Can withstand 3.2g
- Flight speed of 94 ft/s at altitude of 60,000 ft
Airfoil: LA2573A

- Modified Liebeck Airfoil
- Max t/c = 0.137
- x/c of max t = 0.288
- Max camber/c = 0.032
- x/c of max camber = 0.261
Pressure Distribution

Angle of Attack = 7°
Lift Curve

- $C_{La} = 6.97$
- $C_{Lmax} = 1.3$
- Stall occurs at $\alpha = 11^\circ$
- Zero lift angle $\alpha = -0.82^\circ$
Moment Curve

- $C_{ma} = -0.03$
- Requires positive $C_m$ to trim so must not exceed $\alpha = 18^\circ$
Drag Polar

- $C_{D0} = 0.014$
- $(L/D)_{\text{max}} = 25$
- Best performance of airfoil when $CL$ does not exceed 1.2 ($\alpha = 10^\circ$)
Wind Tunnel Data

Wind tunnel data courtesy of R.H. Liebeck
Analysis in AVL

- Mach = 0.097
- $C_D = 0.017$
- $CL = 0.745$
- # Panels = 20 x 6
- Wing tip panels had 1° twist
Span Loading at $\alpha = 7^\circ$
## Derivatives

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### Derivatives, $\frac{3}{4}$ chord elevator

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Results

- $e = 0.92$
- Neutral Point = 26% of chord
- $(C_{l\beta}C_{nr})/(C_{l\gamma}C_{n\beta}) = -3.82$
  - This must be greater than 1 to be spirally stable

Photo courtesy NASA Dryden Photo Gallery
Optimization of Planform

- **Objectives:**
  - Maximize Power
  - Minimize Weight
  - Minimize Drag

- **Design Variables:**
  - Spans of center, mid, and tip panels
  - Chord

- Create model in Model Center using MATLAB modules for weight, drag and power

- Use the Darwin genetic algorithm to perform multi-objective optimization
Modules

- Weight: Assumed evenly distributed
- Drag: Assumed a drag polar, \( \frac{C_D}{\pi ARe} = C_{D0} + \frac{C_L^2}{\pi ARe} \)
- \( C_{D0} \): Used equations from ‘friction’ to obtain \( C_{D0} \), assuming a high laminar to turbulent ratio
- Power: Solar panels cover 75% of the upper surface

Constants for Optimization:
- \( e = 0.92 \) (from AVL)
- \( \rho = 0.0002256 \text{ sl/ft}^3 \) (60,000 ft)
- \( \mu = 0.297 \cdot 10^{-6} \text{ sl/ft-s} \)
- \( M = 0.097 \) (\( V=94 \text{ ft/s at 60K ft} \))
- \( FF = 2.12 \)
- \( Q = 1.0 \)
- \( W/S = 0.694 \text{ psf} \)
- \( P/S = 13.5 \text{ W/ft}^2 \)
Optimization Results

Pareto designs are those that have a better value for at least one objective function than similar designs.

Nearly linear relationship between objective functions for the non-dominated frontier.

Ideally look for designs with comparatively higher power than those with similar weight and drag. These designs are referred to as “knees in the curve.”
## Best Design for W=550 Pounds

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<th>Optimized</th>
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<tr>
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<td>Power</td>
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<td>Center b</td>
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<td>Mid b</td>
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<tr>
<td>Chord</td>
<td>8 ft</td>
<td>8.96 ft</td>
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References

- Solar-Powered Research and Dryden Fact Sheet, avail. at NASA DFRC website:
  [http://www.nasa.gov/centers/dryden/news/FactSheets/FS-054-DFRC.html](http://www.nasa.gov/centers/dryden/news/FactSheets/FS-054-DFRC.html)
- NASA Dryden Photo Gallery, avail at NASA DFRC website:
- UIUC Airfoil Coordinates Database, avail. at UIUC website:
  [http://www.ae.uiuc.edu/m-selig/ads/coord_database.html](http://www.ae.uiuc.edu/m-selig/ads/coord_database.html)
- The Incomplete Guide to Airfoil Usage, avail. at UIUC website:
  [http://www.ae.uiuc.edu/m-selig/ads/aircraft.html](http://www.ae.uiuc.edu/m-selig/ads/aircraft.html)
- Xfoil Source and Materials:
- AVL Source and Materials:
- MATLAB, courtesy MathWorks
- Model Center, courtesy Phoenix Integration

Photo courtesy NASA Dryden Photo Gallery
$P_{total} = (6)(1.5hp) = 9hp \times \frac{550 \text{ft}lb/s}{1hp} = 4950 \text{ft}lb/s$

$T = \frac{P}{V} = \frac{4950 \text{ft}lb/s}{94 \text{ft/s}} = 52.66 \text{lb}$

$T/W = \frac{52.66}{550} = 0.096$

$P/W = (9hp)(832 \text{W/hp})/550 \text{lb} = 13.6 \text{Watts/lb}$