Department of Mechanical Engineering and Aeronautics
Laboratory of Technology & Strength of Materials

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ
UNIVERSITY OF PATRAS

Division of Applied Mechanics, Technology of Materials & Biomechanics

DIPLOMA THESIS

STRUCTURAL ANALYSIS OF A COMMERCIAL AIRCRAFT WING WITH DISTRIBUTED PROPULSION

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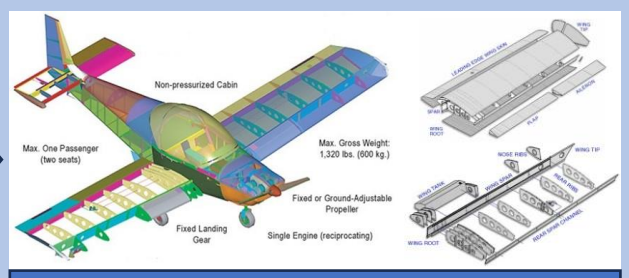
A.M.: **1067248**

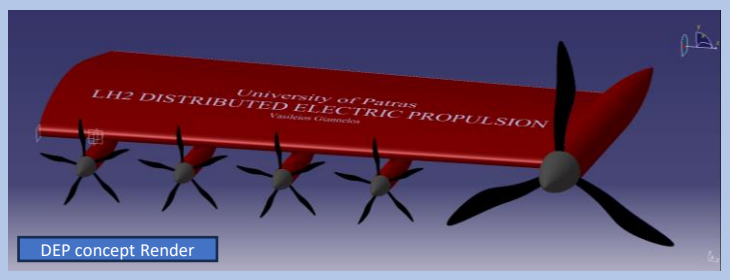
Inspiration from NASA's experimental X-57 Maxwell



Diploma Thesis implementation on Zenith Zodiac CH 650 B

CONCEPT

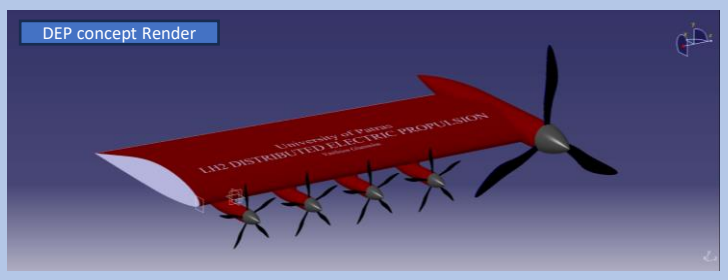
- Wings equipped with **Distributed Electric Propulsion** system
- Powered by **liquid Hydrogen Fuel-Cell**
- Two **Cruise** motor-propeller units
- Eight **High-Lift** motor-propeller units
- Aircraft Gross Weight increased from 600kg to **800kg**
- Cruising Power upped to **160HP from 120HP**
- **STOL capabilities** provided by High-Lift units' **additional 112HP**
- **Foldable High-Lift propellers** during Cruising to increase efficiency



DEP concept Render

Wing Structural Analysis on Zenith Zodiac CH 650 B's
- **Reference** Original Configuration
- New **DEP** Configuration

WING STRUCTURAL ANALYSIS using two methods:
- **Analytical** *(Microsoft Excel)*
- **FEA** *(ANSYS Workbench)*



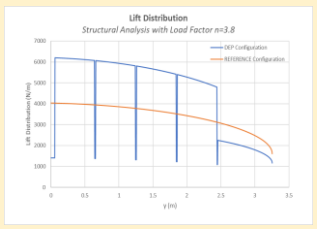
ANALYTICAL

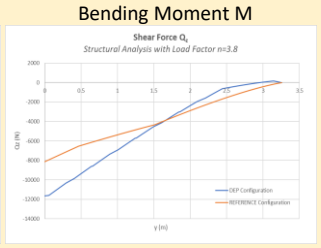
Discretization in Microsoft Excel

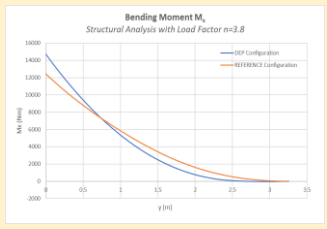
Wingspan step of $h = 0.005m$
Wingspan discretization in 650 sections using 651 points

Calculations in Microsoft Excel

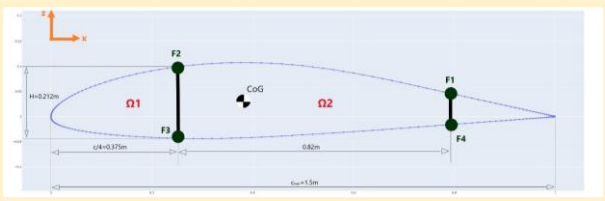
Airfoil & Wing Coefficients from Airfoil Data
Schrenk Chord Distribution
Aircraft Speed from Load Factor $n = 3.8$
Propeller Slipstream Velocities (DEP config.)
Lift & Drag Distributions, Inertial Distributions, Load Distributions
Back-to-Back Computational Integration
Shear Force Q
Bending Moment M



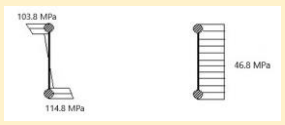




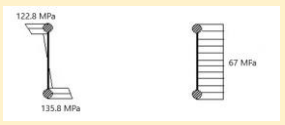
Mean Chord Airfoil Surface Section
Pitching Moment, Torsion Moment
Shear Flows due to Torsion, Shear Flows due to Shear



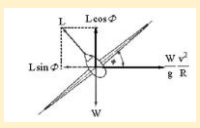
Structural Analysis



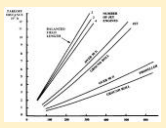
Spar Flanges Normal Stresses
Spar Web Shear Stress
Airfoil Section Shear Stresses
Equivalent (Von Mises) Stresses
Wingtip Deflection
Wing Root Bolt Stresses (Steel)



Performance Calculations



Turning Radius at 3.8g Correctly Banked Turn
Stall Speed
Take-Off Distance



STRUCTURAL	REFERENCE CONFIGURATION	DEP CONFIGURATION
MAX PITCHING MOMENT (WITH LOAD FACTOR) [NM]	952	1465
MAX TORSION MOMENT (WITH LOAD FACTOR) [NM]	2740	3635
MAX AERODYNAMIC LIFT (WITH LOAD FACTOR) [N]	11217	15041
MAX AERODYNAMIC DRAG (WITH LOAD FACTOR) [N]	166	223
MAX SHEAR FORCE QZ [N]	8145	11666
MAX BENDING MOMENT MX [NM]	12449	14730
MAX SHEAR FORCE QX [N]	166	223
MAX BENDING MOMENT MZ [NM]	247	304
MAX FLANGE NORMAL STRESS [MPA]	114.8	135.8
MAX WEB SHEAR STRESS [MPA]	46.3	67
MAX SKIN SHEAR STRESS [MPA]	32.1	42.2
MAX EQUIVALENT STRESS [MPA]	118	143
MINIMUM SAFETY FACTOR	2.3	1.9
WING TIP DEFLECTION [MM]	78.4	71.55

PERFORMANCE	REFERENCE CONFIGURATION	DEP CONFIGURATION
MTOW [KG]	600	800
MAX POWER [HP]	120	272
CRUISE POWER [HP]	120	160
ANALYSIS LOAD FACTOR	+3.8	+3.8
CORRECTLY BANKED TURN ANGLE (DEG)	74.74	74.74
TOTAL LIFT (WITH LOAD FACTOR) [N]	11217	15041
LIFT LEVER ARM (TO FUSELAGE AXIS) [M]	2.1	1.82
STALL SPEED (NO FLAPS, WITH LOAD FACTOR) [KM/H | KNOTS]	195 | 105.3	115 | 62
MINIMUM MANEUVER RADIUS (WITH LOAD FACTOR) [M | FT]	81 | 265.75	28.5 | 93.5
STALL SPEED* [KM/H | KNOTS]	70 | 37.8	63 | 34
TAKEOFF DISTANCE* [M | FT]	152 | 500	107 | 350

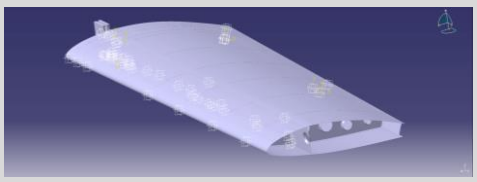
Material: **Al6061-T6**

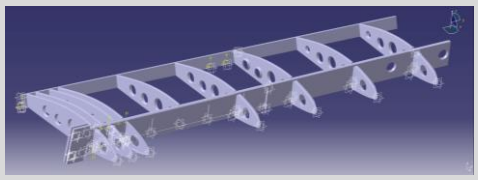
CONCLUSION

- Stress Concentration Alleviation makes a Distributed Electric Propulsion wing a better configuration from a structural perspective.
- Distributed Electric Propulsion offers significant Performance improvement, STOL capabilities, reduced Noise.
- Liquid Hydrogen Fuel-Cell offers Zero-Emissions, a significant step towards sustainability and independence on fossil fuel.

FEA

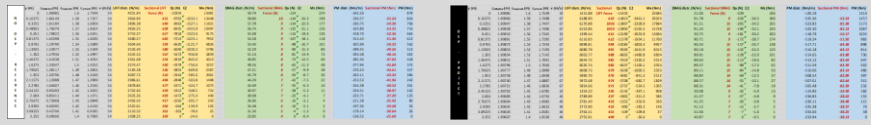
High-Fidelity Wing Design in CATIA V5





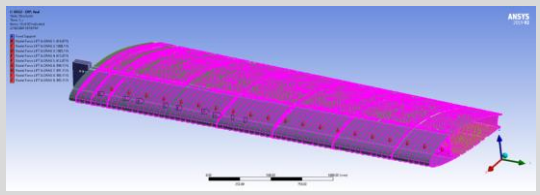
Material: Al6061-T6

Sectional Aerodynamic Loads calculation in Microsoft Excel



- Wingspan discretization in 20 sections using 21 points
- Lift Force, Drag Force and Pitching Moment calculation per section
- Manual insertion in ANSYS through "Nodal Force" and "Moment"

Static Structural Modeling in ANSYS Workbench



- Mesh Generation
- Boundary Conditions, Forces, Moments, Inertial Loads
- Solution setup (Stresses, Deformation etc.)

Finite Element Analysis in ANSYS Workbench

Wing Equivalent Stress, Wing Max Shear Stress, Spar Normal Stress, Wing Total Deformation for Reference config. (LEFT) and Distributed Electric Propulsion config. (RIGHT)