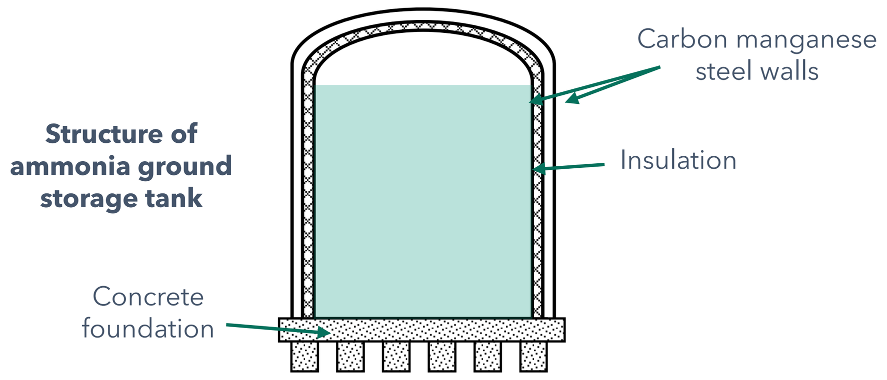
Ammonia-Powered Regional Aircraft

Main Infrastructure Changes

Fuel Storage:
+ Insulated tanks with cooling system to keep fuel under -33˚C
+ Heated foundation due to lower fuel storage temperature
+ Ammonia leak detectors required
+ Minimum safety distance of 150m required

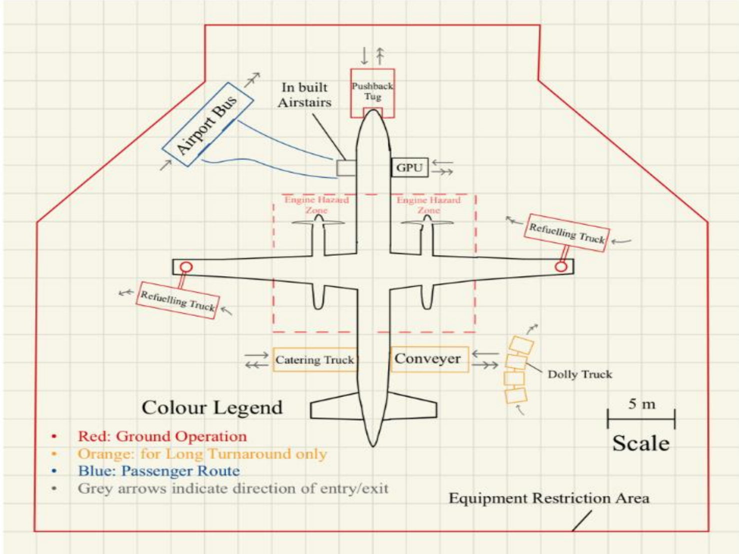
Refuelling
+ Hydrant refuelling system/separate refuelling area needed for safety
+ If refuelling trucks are used, it needs to have refrigeration

Airport Management:
+ Hazmat emergency response unit required on-site
+ Independent drainage system required for chemical waste
+ Gas filters installed on airport ventilation system

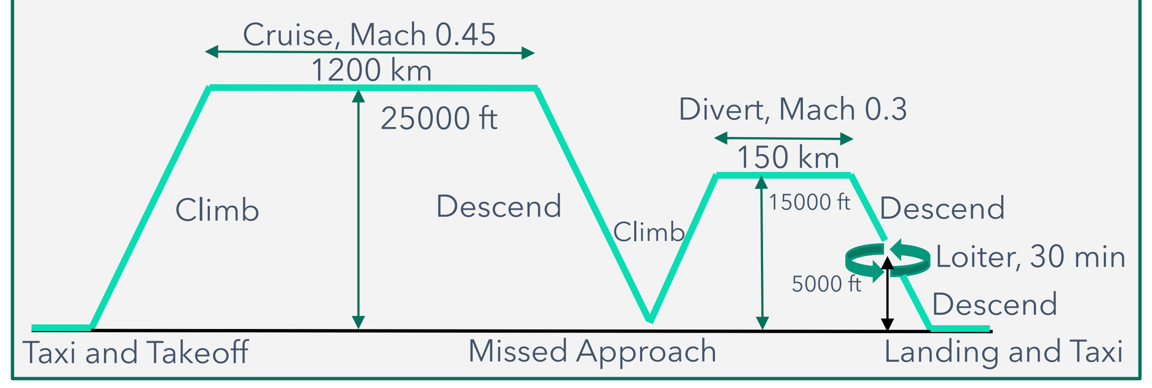


Key Infrastructure Parameters

Capital Expenses:	5% to 31% higher
Operating Expenses:	16% to 110% higher
Carbon Emissions:	Up to 92% reduction
Refuelling Time:	32 to 60 minutes
Risk Level:	Moderately high



Mission Profile



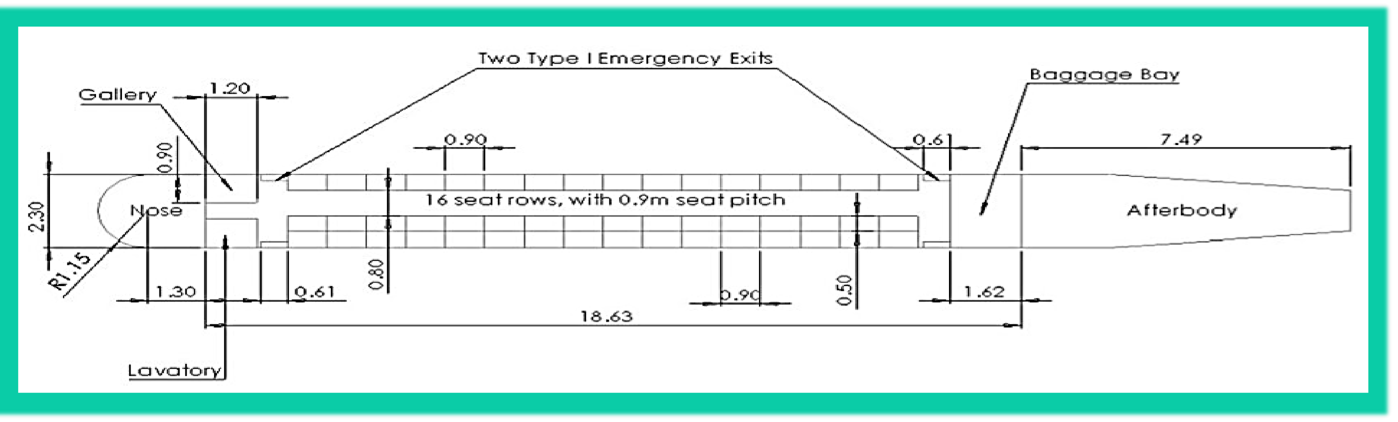
Design Requirements

- 1200 km range
- 48 passengers and luggage
- 1400 m balanced field length
- Follow spirit of FAR-25/EASA requirements

Propulsion System Design Approach

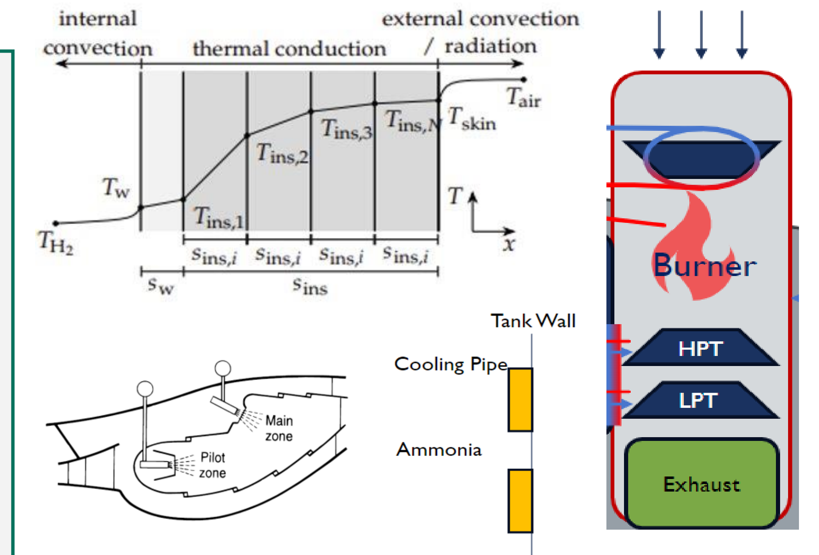
Engine: PW150A Turboprop
Fuel mixture: 30%H_2-70% NH_3 in a pilot zone; Pure ammonia in remaining zones
Catalytic converter: to convert suitable Ammonia into a suitable mixture of Hydrogen, Nitrogen and Ammonia.
Heat exchange system: to satisfy the power required by the catalytic converter working at 400℃
Cooling system: to maintain the temperature of the liquified ammonia at -50℃

Cabin Layout



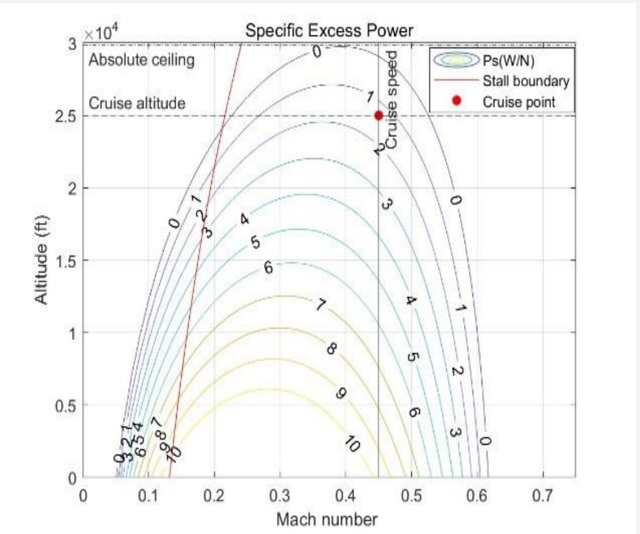
Safety On Board

- Emergency NH_3 removal system in cabin
- Liquid NH_3 storage – safer than vapour form
- Reinforced fuel tanks to mitigate damage



Aircraft Performance

Range:
1255 km
Balanced field length:
1200 m
Takeoff distance:
1101.7 m
Landing distance:
1087 m
OEI climb gradient:
7.36 %



Design Point

P_0/W_0 (W/N):	23
W_0/S_{ref} (N/m²):	3332

Key Parameters

Overall length :
29.76 m
Fuselage diameter:
2.3 m
Wingspan:
30.36 m
Empty weight:
18601 kg
Fuel weight:
8320 kg
Payload weight:
5044 kg
MTOW:
31965 kg

Main Design Features

Turboprop engines:
+ Best suits range
+ Very efficient for low speed & short haul

Fuel system in wings:
+ Close to the engine
+ Wing bending relief
+ Efficient space utilisation

High wing:
+ Fuel system away from cabin and ground
+ More fuel storage volume
+ Faster turnaround

Conventional fuselage:
+ 2x1 seating reduces drag
+ Passenger comfort & familiarity

Nacelle mounted gear:
+ No overturning issues
+ No bulky housing structures needed

T-tail:
+ Best avoids engine & wing wake disturbances

Ammonia presents a promising solution to decarbonising aviation for a sustainable future

Propulsion System Design Considerations

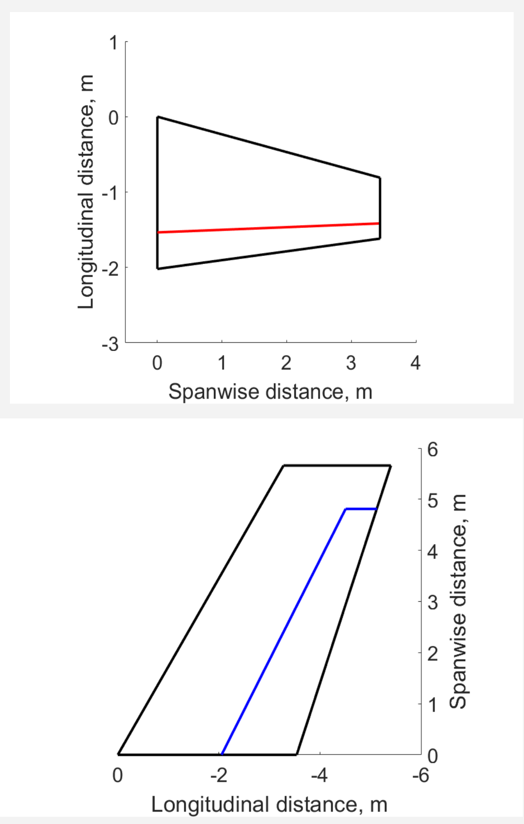
- **Power requirement of the catalytic cracker is reduced** to 162kW by injecting the fuel mixture into the pilot zone and pure ammonia into the rest combustion zones.
- **To reduce & minimize NO_x**: A fuel staging in the primary zone is applied. Ammonia is injected directly into the exhaust for reduction
- **Cooling system**: A cooling system integrated alongside Cryogel (FRAB) is utilised. A commercial refrigerated recirculating chiller, pumping propylene glycol coolant to the fuel tanks at varying mass flow rates

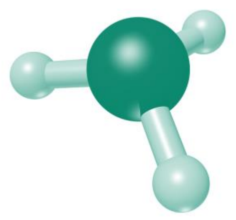
Overall Engine Efficiency = 30 %

Key Engine Parameters

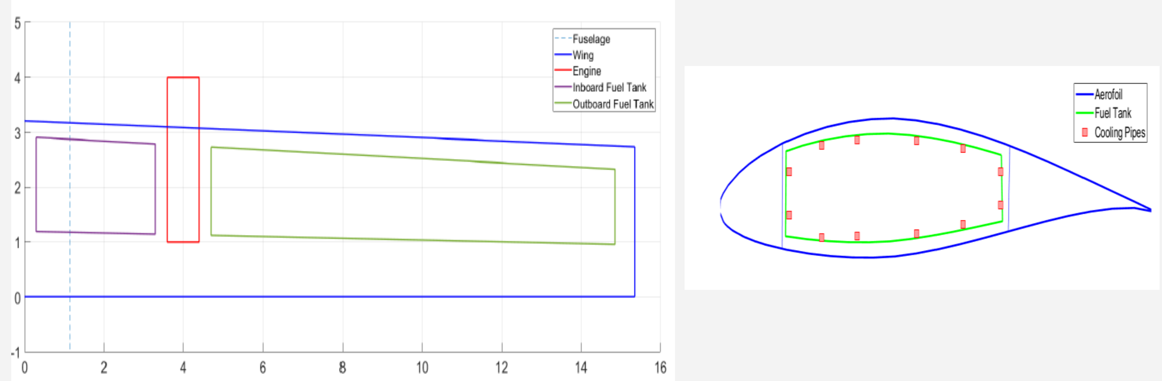
Final Mixture LHV :	49 MJ/kg
Ammonia LHV:	18.6 MJ/kg
Fuel Consumption Rate:	0.51 kg/s
TSFC:	2.13x10^{-5}
Primary Zone Air %:	15%
Secondary Zone Air %:	20%
Cool Linear Walls Air %:	40%
Dilution Zone Air %:	25%
F/A Ratio:	0.0455
Stoichiometric F/A Ratio:	0.1345
Equivalence Ratio:	0.3382
Insulation Thickness:	0.04 m
Outboard Insulation Weight:	220kg/wing
Inboard Insulation Weight:	75kg/wing
$\dot{m}$ Coolant Outboard Tank:	1.23kg/s
$\dot{m}$ Coolant Inboard Tank:	0.90kg/s
Recirculating Chiller:	Lneya LT-65A1N
Mass of Chiller:	325 kg/wing
Catalyst Length:	0.5m
Catalyst Radius:	0.078m
Catalyst + Fin Mass:	40kg
Fin Thickness:	0.001m
Fin Height:	0.12m

Tail Geometry





Fuel Tanks



Structural Considerations

- The materials used for the construction of the aircraft's fuselage, wing and fuel tanks were aluminium alloys from different series: Al7255 T7751, Al7068 T6511, Al2024 T861, Al5182 H19 and Al8019.
- Additional coating on the interior of the fuel tanks that would act like a supplementary barrier against corrosion was applied, vinyl ester coating was used.
- Manufacturing methods chosen for the fuselage included press forming, CNC milling and extrusion for better accuracy and mechanical properties.
- CFRP used to manufacture empennage.

Fuselage Weight Breakdown:

Skin	Stringers	Light Frames	Heavy Frames
755 kg	1488 kg	116 kg	1550 kg

Wing Weight Breakdown:

Stringer Panel and Ribs	Spars	D-section	Total
1196 kg	444 kg	17 kg	1657 kg

Tail Weight Breakdown:

Tail	Skin	Spars	Ribs	D-section	Total
Horizontal	13.58 kg	8.18 kg	4.29 kg	7.80 kg	59.7 kg
Vertical	28.16 kg	22.19 kg	9.38 kg	19.44 kg	79.2 kg

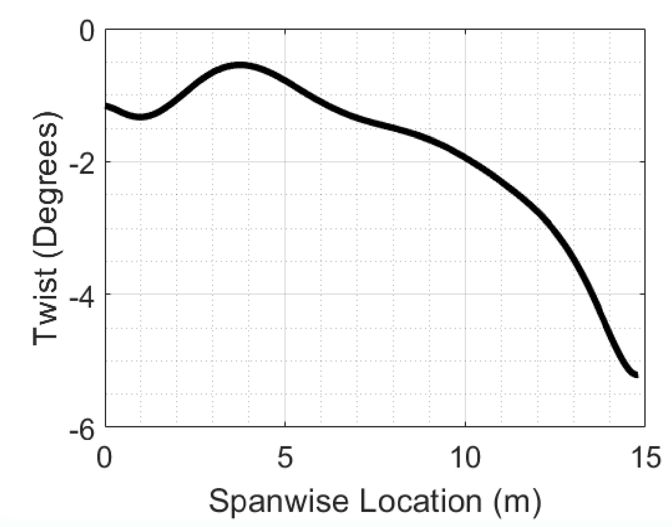
Aerodynamic Design Features

Thick aerofoil:
+ Reduce structural weight
+ Improved low speed aerodynamic efficiency
+ ample space left for fuel storage
+ gentle stall behaviour

Customized geometric twist (seen below):
+ Excellent fit towards elliptical lift distribution
+ Washout to prevent tip stall
+ Accounts for unusual lift distribution caused by propeller wash-wing interaction
+ Yields 19.6% reduction in induced drag worst case scenario.

Fairing:
+ Reduces zero lift drag by reducing interference between wing and fuselage

HLD:
+ Double slotted flaps + Slats

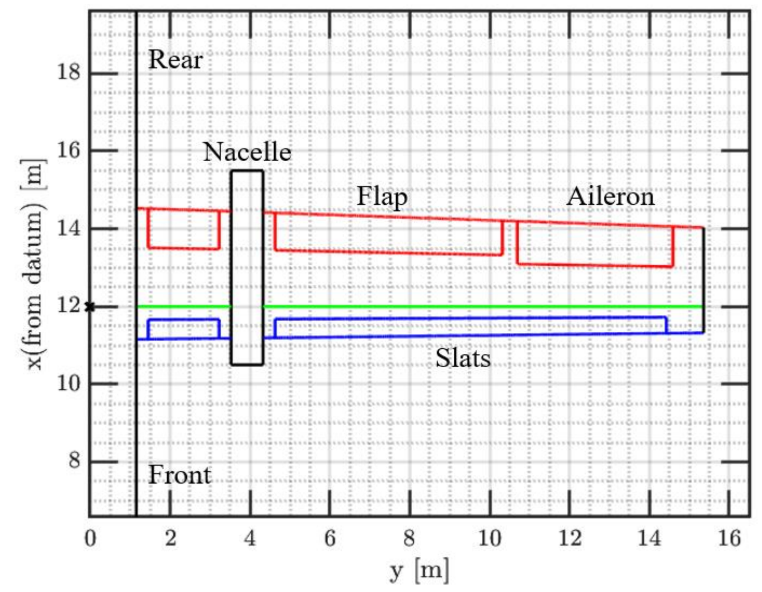


Wing Planform Geometry

Aspect ratio: 10
Dihedral: 1˚
Washout: -4.5˚
Aerofoil: NACA 64(3)-618
Taper ratio: 0.79
Geometric twist: customized
S_{ref} : 87.6 m2
Mean chord length: 3.04 m

Aerodynamic Performance Indices

$C_{L_{takeoff}}$: 2.107
$C_{L_{cruise}}$: 0.616
$C_{L_{landing}}$: 1.754
Lift curve slope: 6.12
$V_{stall,cruise}$: 69.95 ms-1
$C_{D_{takeoff}}$:0.2282
$C_{D_{cruise}}$: 0.0344
$C_{D_{landing}}$: 0.2366
Moment curve slope: -0.028
$V_{stall,landing}$: 44.89 ms-1



Flight Testing

Findings:
- Predictable and controllable behaviour in OEI
- Difficult to control pitch during stall recovery due to ineffective elevator
- Loss of aileron authority and eventual complete loss of roll control in power-on stalls

Proposed design improvements:
- Addition of spoilerons on inboard wing sections
- Horizontal tail redesign to facilitate larger elevator

Modelling limitations:
- Error in experimental vertical tail aerofoil data caused an asymmetric vertical tail lift curve – requires CFD or wind tunnel testing to improve
- Inaccurate propeller modelling due to unavailability of data – requires detailed propeller design from manufacturer or in-house

Stability Characteristics

Static stability
- Static margin varies between 4% - 9% for all load conditions
- Laterally and (Longitudinally) stable
- Satisfy CS-25 requirement for minimum control speed above 1.13 stall speed
- Cons : Excess stability hinders performance

Dynamical stability
- Dynamically stable with satisfactory response
- Acceptable flight handling qualities

Autopilot
- Good overall performance

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