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Austrian Network for Higher Education

University of Applied Sciences

Basic Comparison of Three Aircraft Concepts: Classic Jet Propulsion, Turbo-Electric Propulsion and Turbo-Hydraulic Propulsion

Aerospace Engineering - Master thesis

Master Thesis Defense

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Introduction

Background

- Flightpath 2050 – reduction of carbon emissions by 70%
- Reducing the operating costs for aircraft operators
- Batteries are too heavy for passenger aircraft
- New technologies must not deviate from the crucial aircraft requirements
- Can the efficiency be increased with the technology available currently?

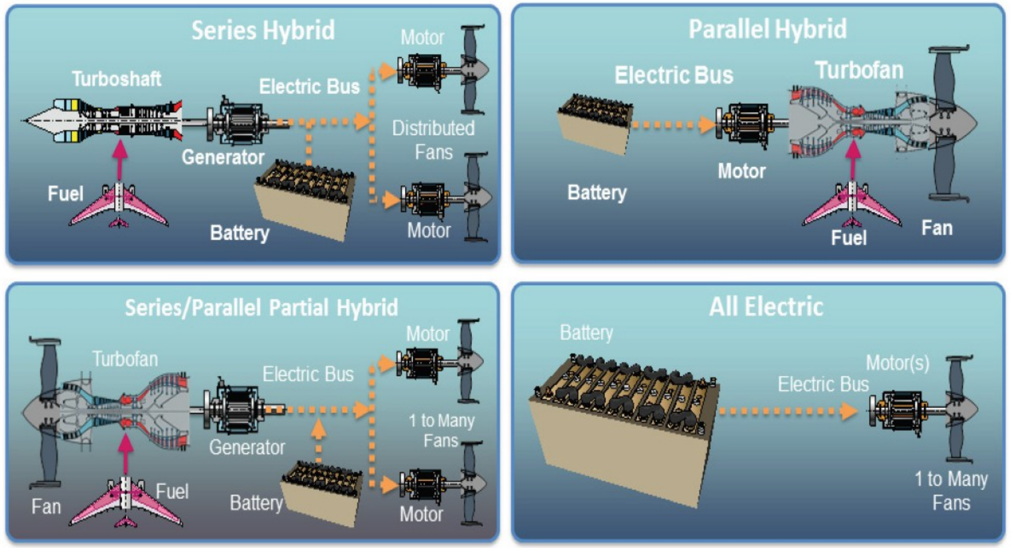

Fig 1: Various Electric propulsion system architectures (NAS 2016)

Introduction

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Research Question

In light of today's propulsion options for passenger aircraft: What is the superior propulsion principle with respect to Direct Operating Costs and environmental impact? Turbo-electric propulsion, turbo-hydraulic propulsion or the established reference, the turbofan engine?

Top Level Aircraft Requirements of A320 :

- Number of Passengers : 180
- Range : 1700 NM
- Cruise Mach number : 0.78

All Turbo-Electric/Hydraulic Propulsion

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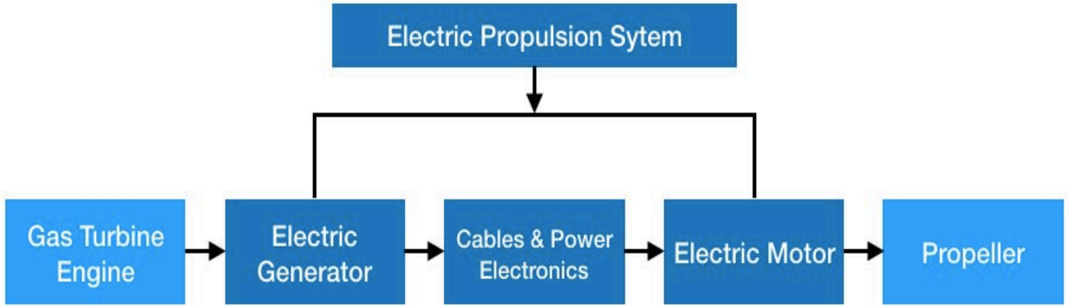

Fig 2: Turbo-electric Engine Architecture (NAS 2016)

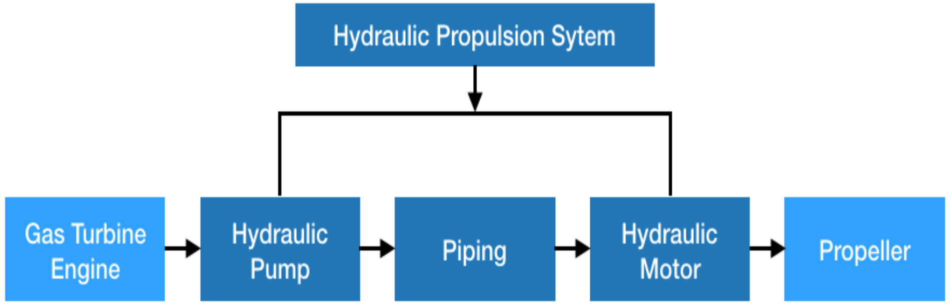

Fig 3: Turbo-hydraulic Engine Architecture

Better Efficiency

Better Power-to-Weight Ratio

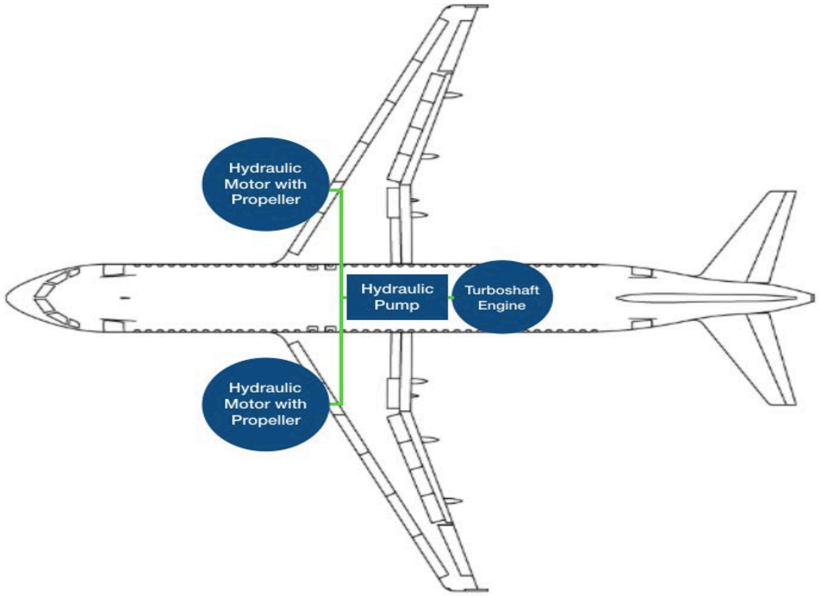

Fig 4: Turbo-Hydraulic Propulsion System

Partial Turbo-Electric/Hydraulic Propulsion

- Power extracted from the shaft of the Turbofan engine
- Cruise thrust required ~ 20% Take-off thrust
- Electric/Hydraulic motors operated only during cruise
- New TSFC calculated with two methods
- Different hybridization levels were investigated

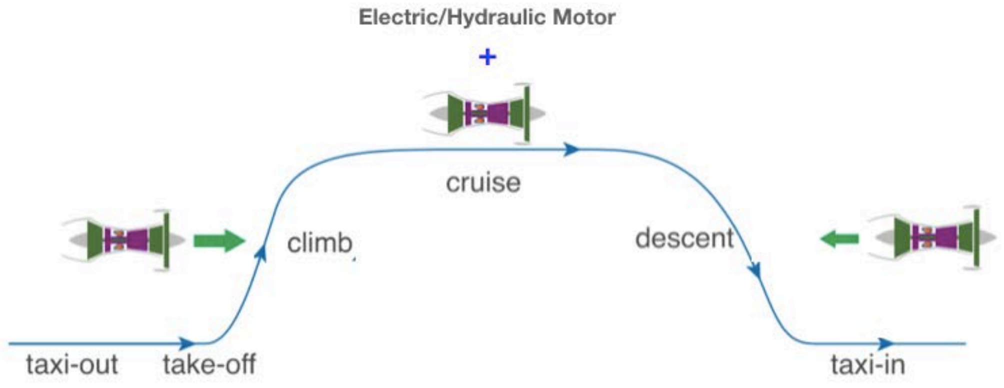

Fig 5: Working of Partial Turbo-Hydraulic/Electric System

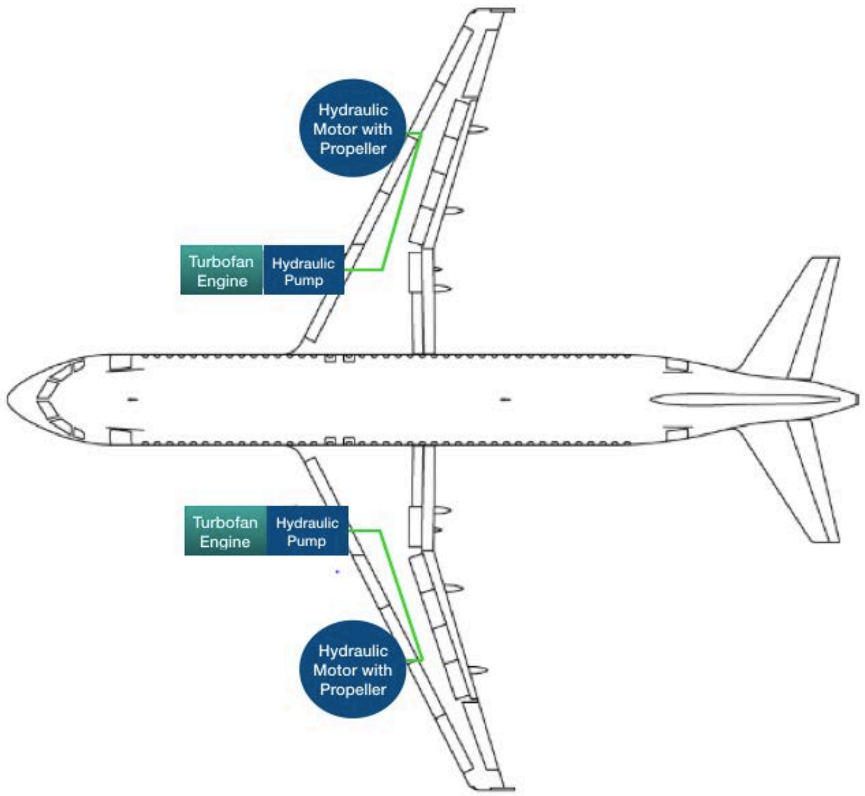

Fig 6: Partial Turbo-Hydraulic/Electric System

Methodology

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All Turbo-Electric/Hydraulic Propulsion

Two Types of Gas Turbine Engine:

- Turboprop
- Turboshaft

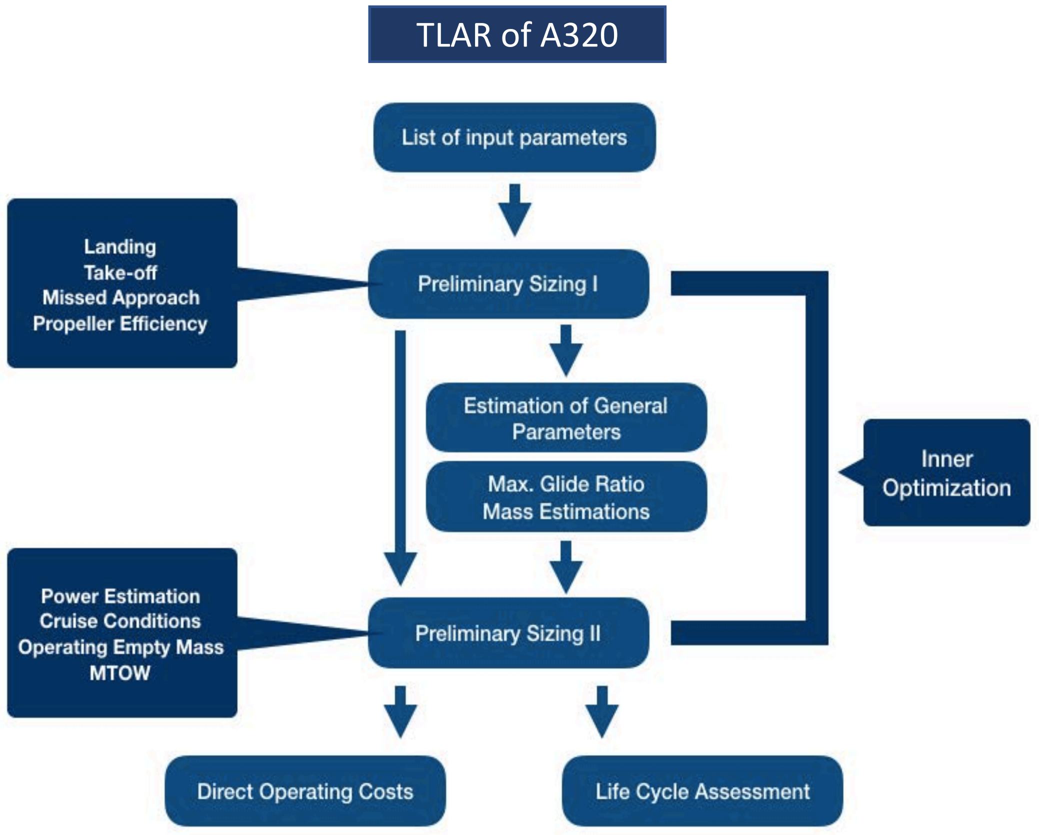

Fig 7: Aircraft Design Methodology for All Turbo-Electric/Hydraulic Propulsion

Methodology

Partial Turbo-Electric/Hydraulic Propulsion

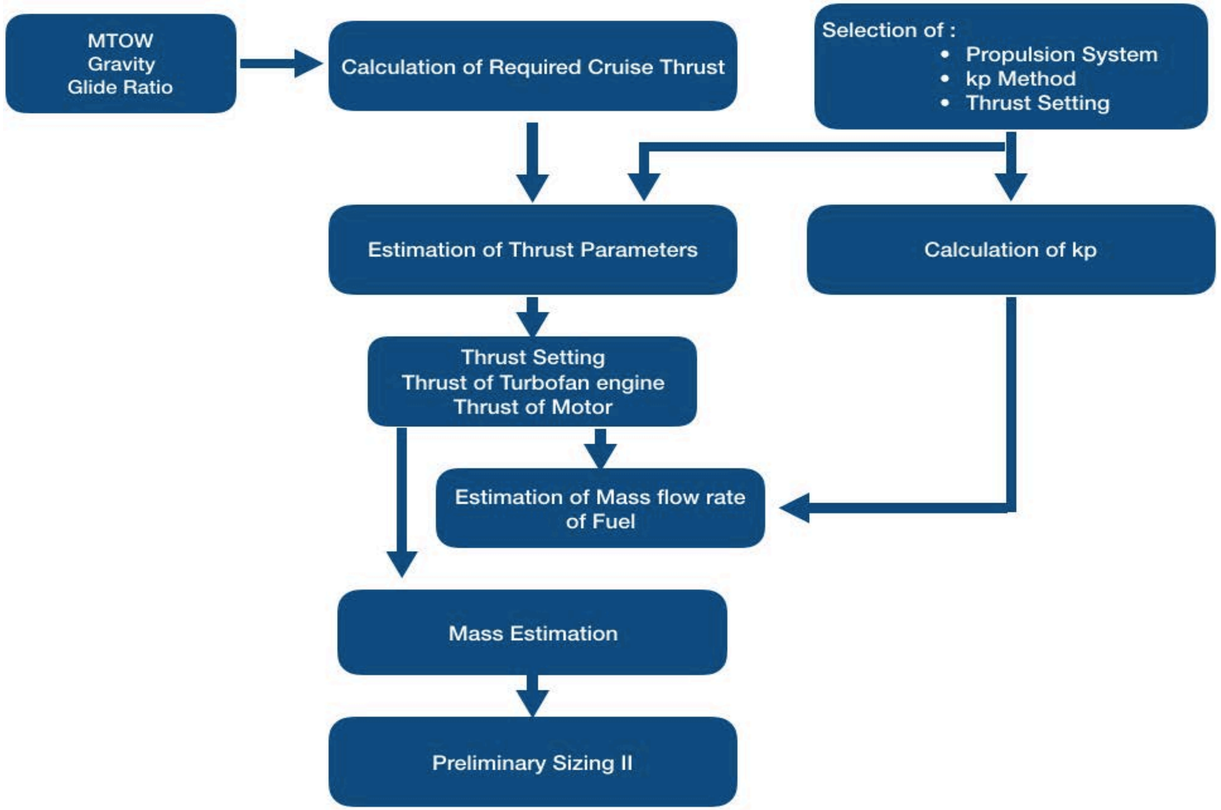

Fig 8: Partial TE/TH Design Methodology

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Preliminary Sizing Tool

Calculation Tool

- Getting Started
- Calculation Tool :
  - Aircraft Design Type
    - Normal
    - All Turbo-Electric/Hydraulic
    - Partial Turbo-Electric/Hydraulic
  - Preliminary Sizing I
  - Maximum Glide Ratio
  - Mass Estimation
  - Preliminary Sizing II
  - Direct Operating Costs
  - Results

1. AIRCRAFT DESIGN TYPE SELECTION

This section allows the user to choose and specify the type of propulsion system of the aircraft

Choose>>	Propulsion System	All Turbo-Hydraulic
Choose>>	Type of Gas Turbine Engine	Turboshaft

2. PRELIMINARY SIZING I

This section allows the user to estimate the thrust/power-to weight ratio and wind loading with simple input paramters

s_{LFL}	Landing field length	1480	m
k_{APP}	Approach Factor	1.818	$(m/s^2)^{0.5}$
$C_{L,max,L}$	Max. lift coefficient landing	3.14	
m_{ML} / m_{TO}	Mass ratio, landing-take-off	0.88	
s_{TOFL}	Take-off Field Length	1764.84	m
$C_{L,max,TO}$	Max. lift coefficient take-off	2.24	
d_P	Propeller diameter	8.5	m
A	Aspect ratio	9.5	
n_E	Number of engines	2	

3. MAXIMUM GLIDE RATIO IN CRUISE

This section allows the user to input or estimate the max. lift to drag ratio

Choose>>	Given: Maximum glide ratio	Yes
E_{max}	Max. Glide Ratio	17.26

4. MASS ESTIMATION

This section is responsible for the calculation of operating empty mass and mass of the propulsion system.

$m_{OE,ref}$	Operating Empty Mass of the reference aircraft	41244	kg
$m_{E,ref}$	Mass of an engine of reference aircraft	3886	kg

Fig 9: The Calculation Tool

Preliminary Sizing Tool

Results

7. RESULTS

7.1 Aircraft Design

m_E	Engine mass (one engine)	3599.81	kg
m_{OE}	Operating empty mass	40671.62	kg
m_{MTO}	Max. take-off mass	70966.05	kg
V_{CR}	Cruise speed	237.10	m/s
$\eta_{P,CR}$	Propeller efficiency, cruise	0.86	
$P_{S,TO} / n_E$	Power required by one engine	9850669.42	W
E_{max}	Max. glide ratio	17.26	
m_{MTO} / S_W	Wing loading	645.17	kg/m²
S_W	Wing Area	110.00	m²
$P_{S,TO} / m_{MTO}$	Power-to-weight ratio	277.62	W/kg

7.2 Direct Operating Costs

m_{PL}	Trip payload mass	16740	kg
$m_{F,trip}$	Trip fuel mass	7436	kg
C_{DEP}	Depreciation costs	5616098.3	$/year
C_{INT}	Interest costs	4621424.9	$/year
C_{INS}	Insurance costs	383004.7	$/year
C_F	Fuel costs	3096278.1	$/year
C_M	Maintenance costs	5720981.0	$/year
C_C	Staff costs	5137386.5	$/year
C_{FEE}	Fees and charges	10438414.1	$/year
C_{DOC}	Total direct operating costs	35.01	M$/year

Fig 10: Results section in the Calculation Tool

Life Cycle Assessment

- An Excel based Life Cycle Tool
- Developed in the AERO Group at HAW Hamburg.

- Given inputs are :
    - Operating Empty Mass
    - Trip Range
    - Engine Mass
    - Fuel Burn
    - Flight Level
    - Cruise Altitude
    - Number of flights annually

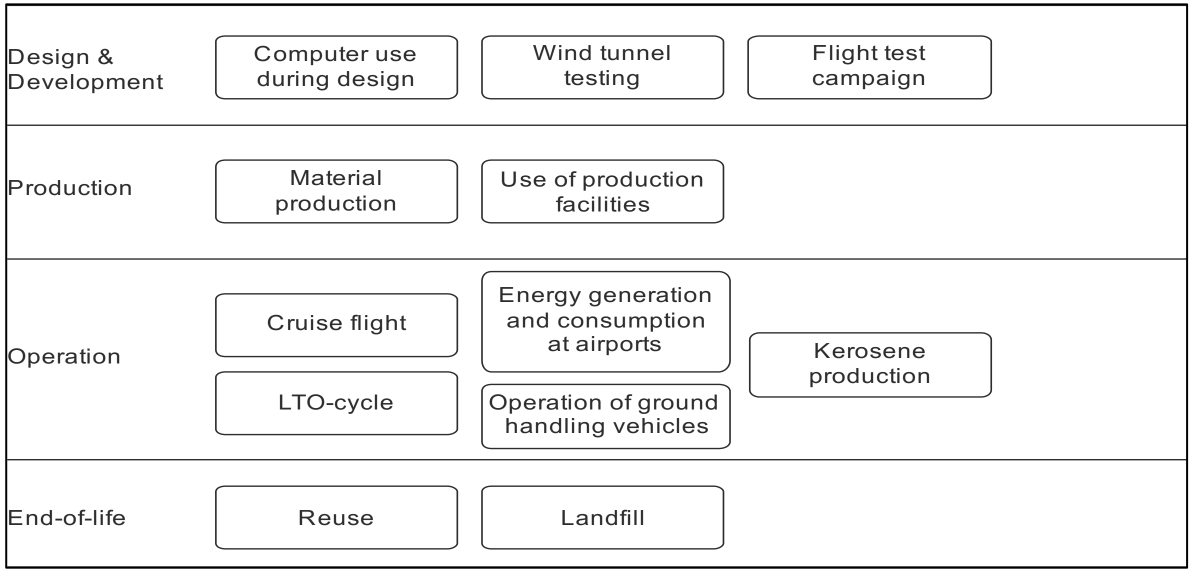

Fig 11: Results section in the Calculation Tool (Johanning 2017)

Results

Turbo-Electric/Hydraulic Propulsion

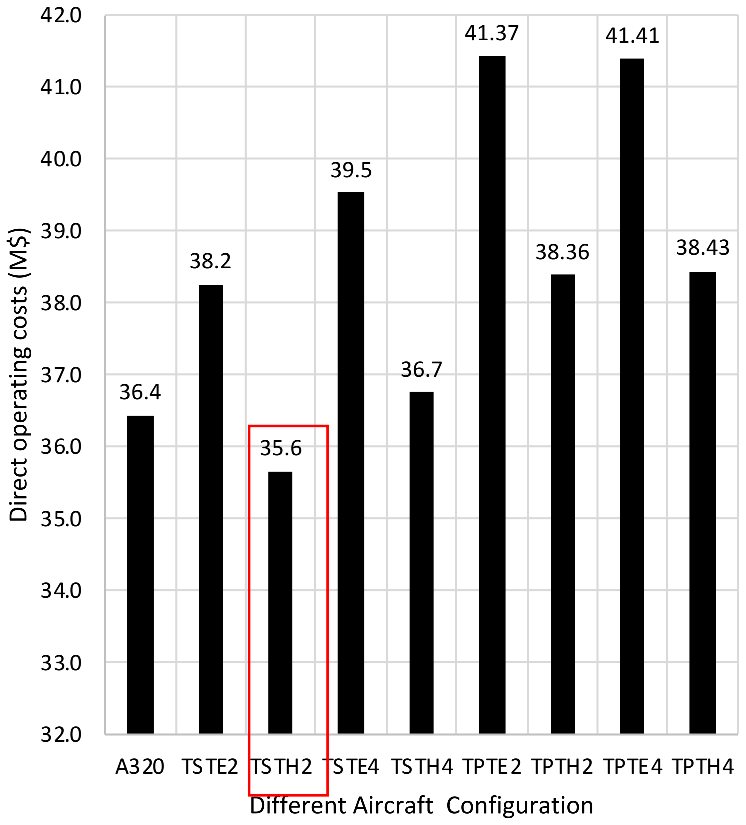

Fig 12: Comparison of Direct Operating Costs and different aircraft configurations

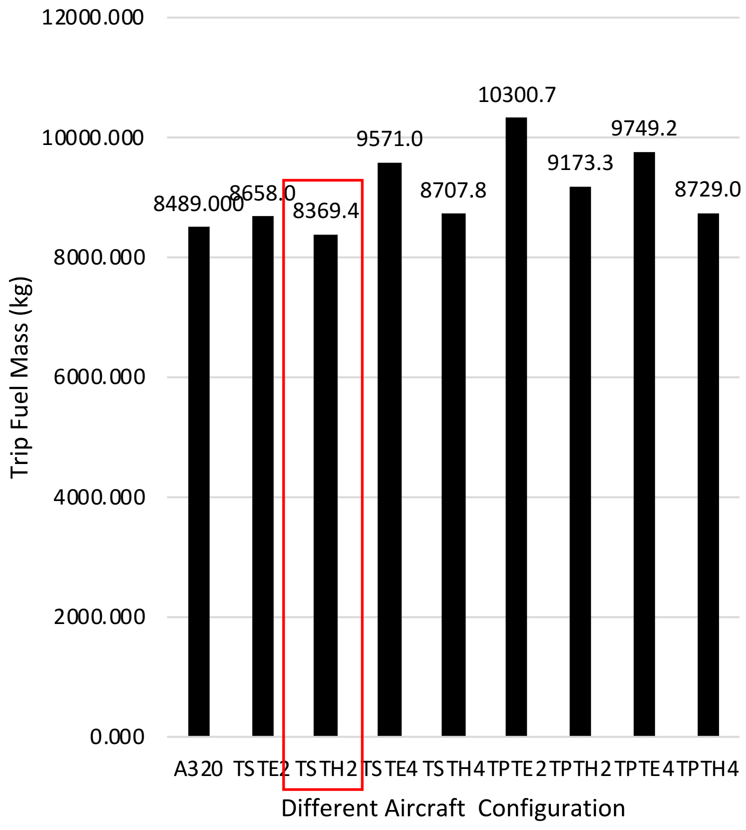

Fig 13: Comparison of Trip Fuel Mass and different aircraft configurations

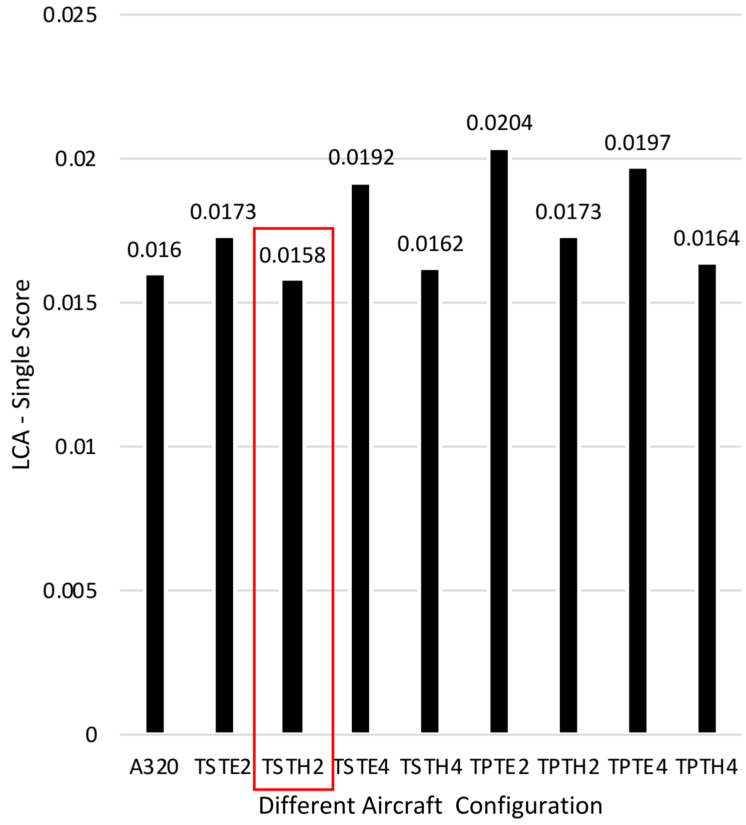

Fig 14: Comparison of Life Cycle Assessment and different aircraft configurations

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Results

Distributed Propulsion System

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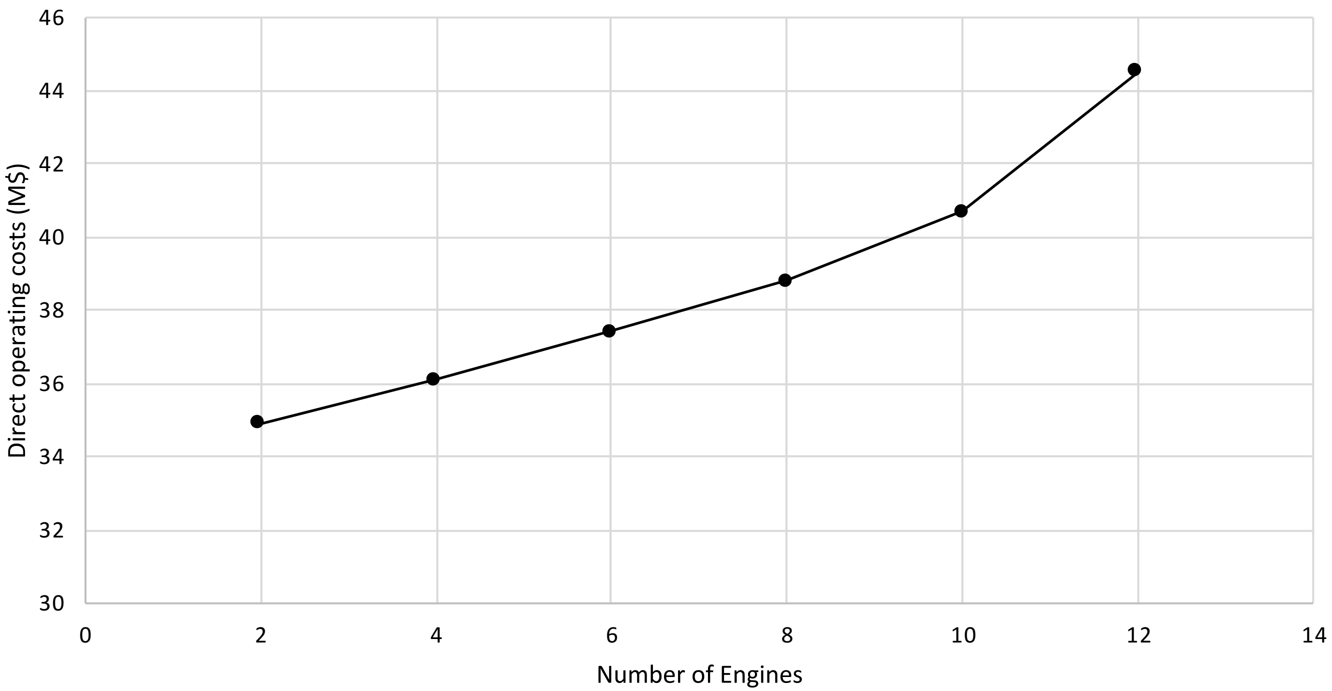
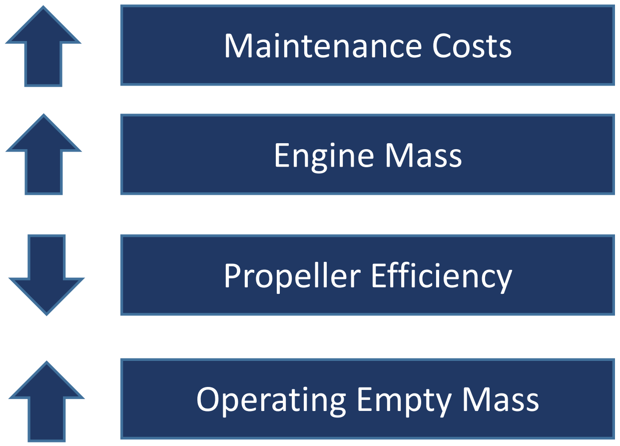


Fig 15: Number of engines against direct operating cost (M$)



Results

Partial Turbo-Electric/Hydraulic Propulsion

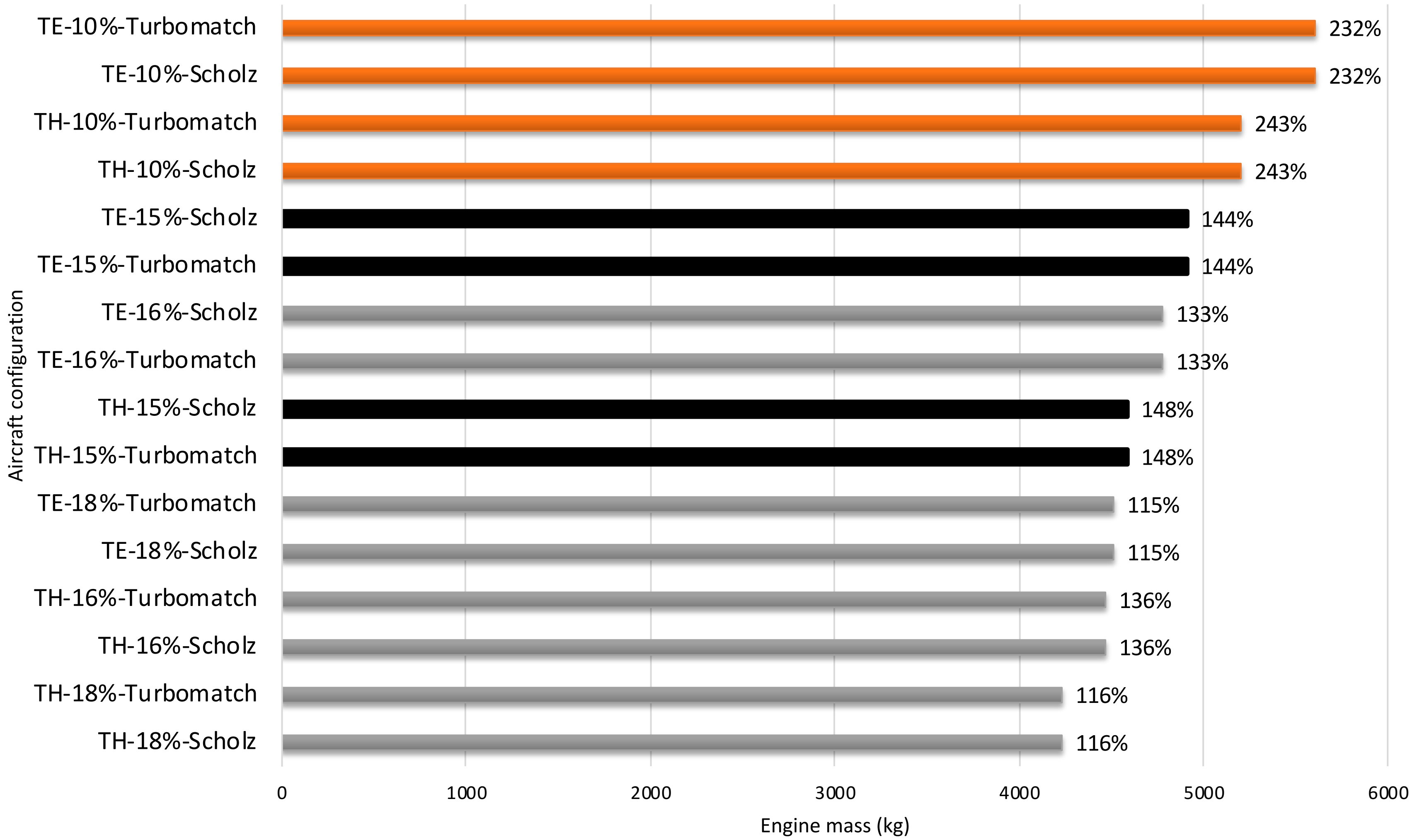


Fig 16: Comparison of aircraft parameters and different aircraft configurations

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Results

Turbo-Electric/Hydraulic Propulsion

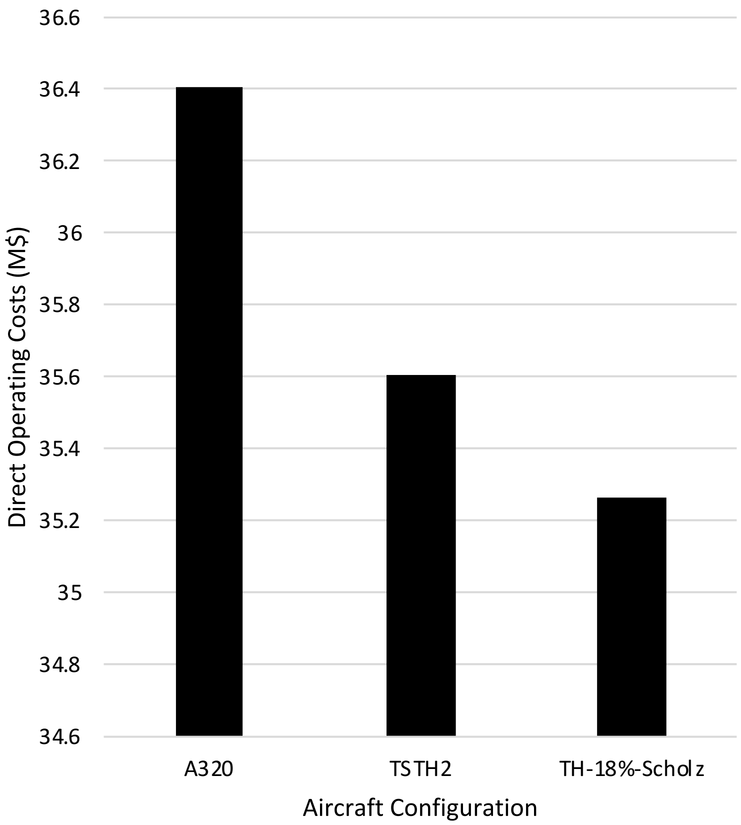

Fig 17: Comparison of Direct Operating Costs and different aircraft configurations

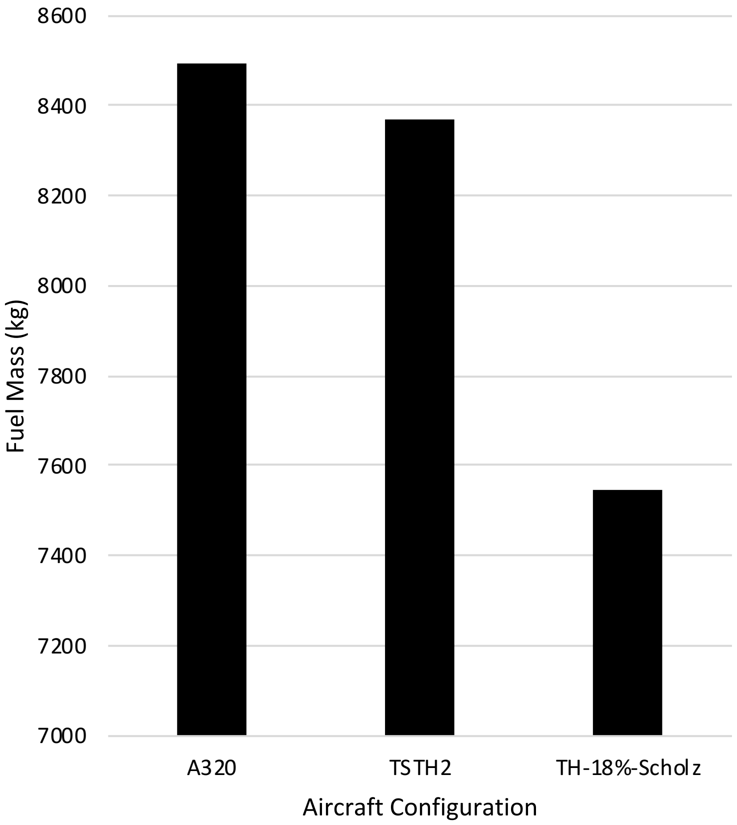

Fig 18: Comparison of Trip Fuel Mass and different aircraft configurations

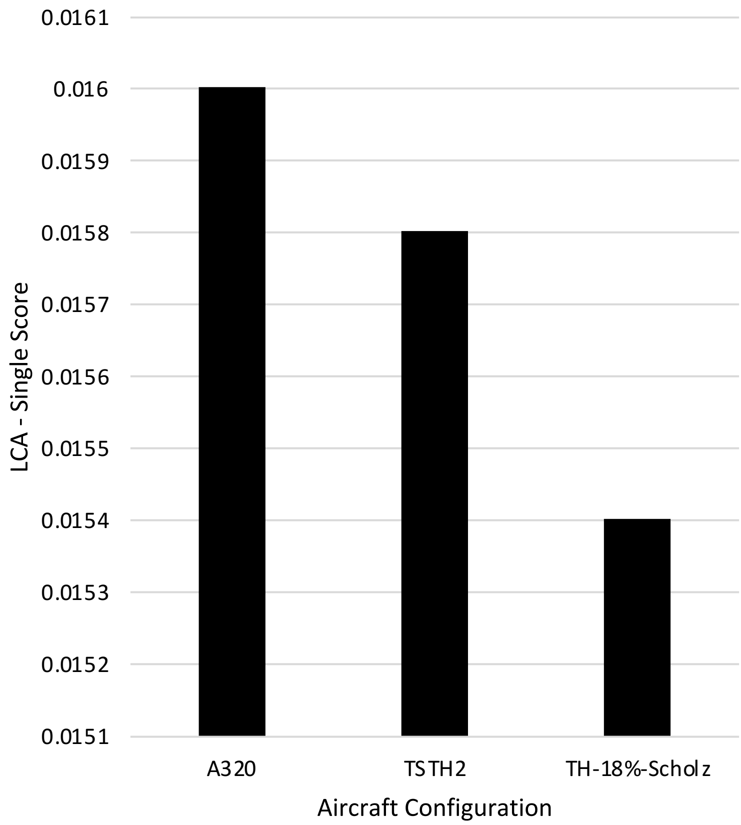

Fig 19: Comparison of Life Cycle Assessment and different aircraft configurations

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Summary

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- A total of 30 aircraft configurations were studied
- Turbo-hydraulic propulsion system with 2 engines and turboshaft engine is the best among TE/TH propulsion.
- Turbo-hydraulic propulsion system producing 10% of thrust in cruise is the best configuration among Partial TE/TH propulsion.

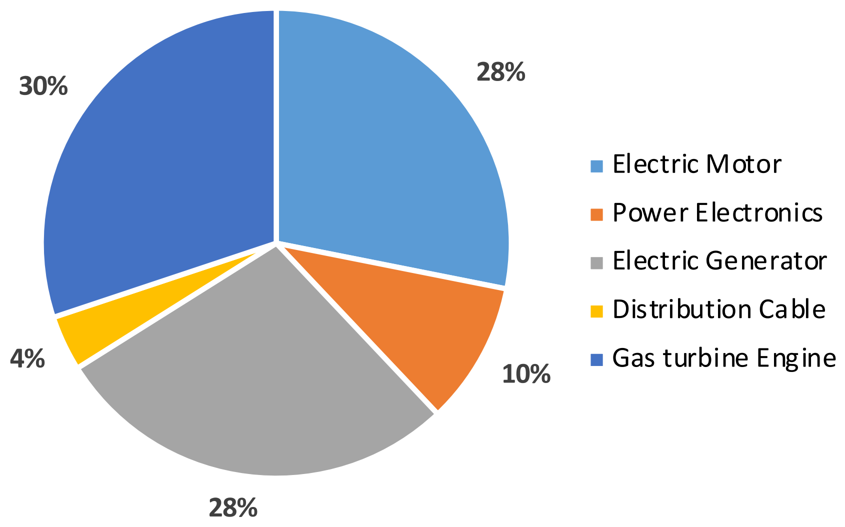

Fig 20: Mass breakdown of turbo-electric propulsion system

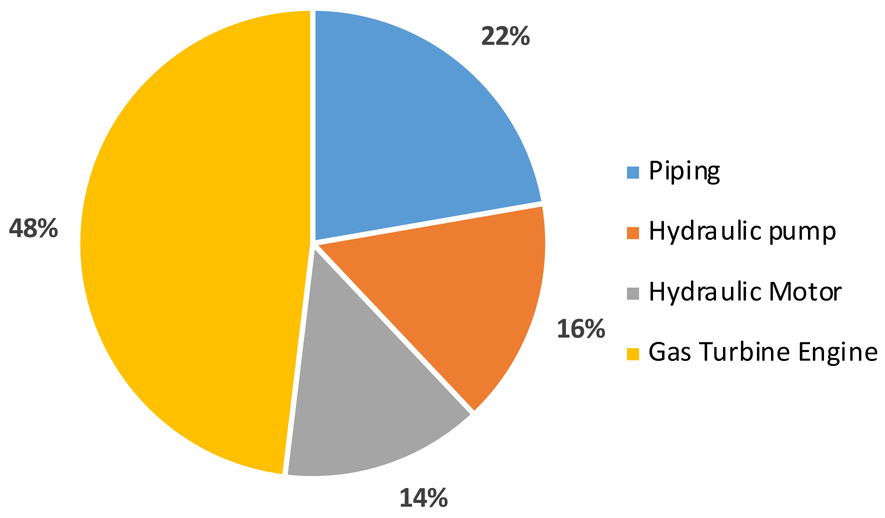

Fig 21: Mass breakdown of turbo-hydraulic propulsion system

Conclusion

- Turbo-hydraulic propulsion is superior to Turbo-electric propulsion
- Partial Turbo-Electric/Hydraulic Propulsion is superior to completely Turbo-Electric/Hydraulic concept
- Improvement in TE by using superconductive material can lead to benefits in mass and efficiency
- Distributed Propulsion System (DPS) might increase the direct operating costs
- Placement of engines can be further studied to increase the aerodynamic advantages

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Thank you for your attention.

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