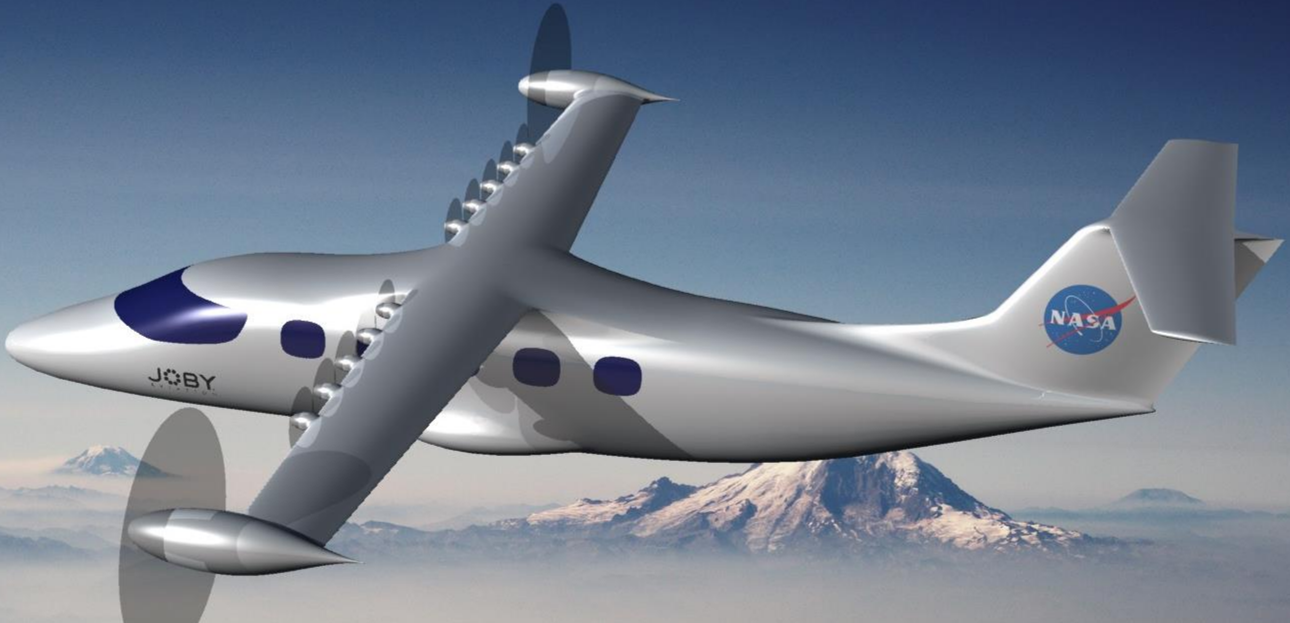



# Advanced Thin-Haul Concept Studies

Alex Stoll and Gregor Veble Mikić
Joby Aviation

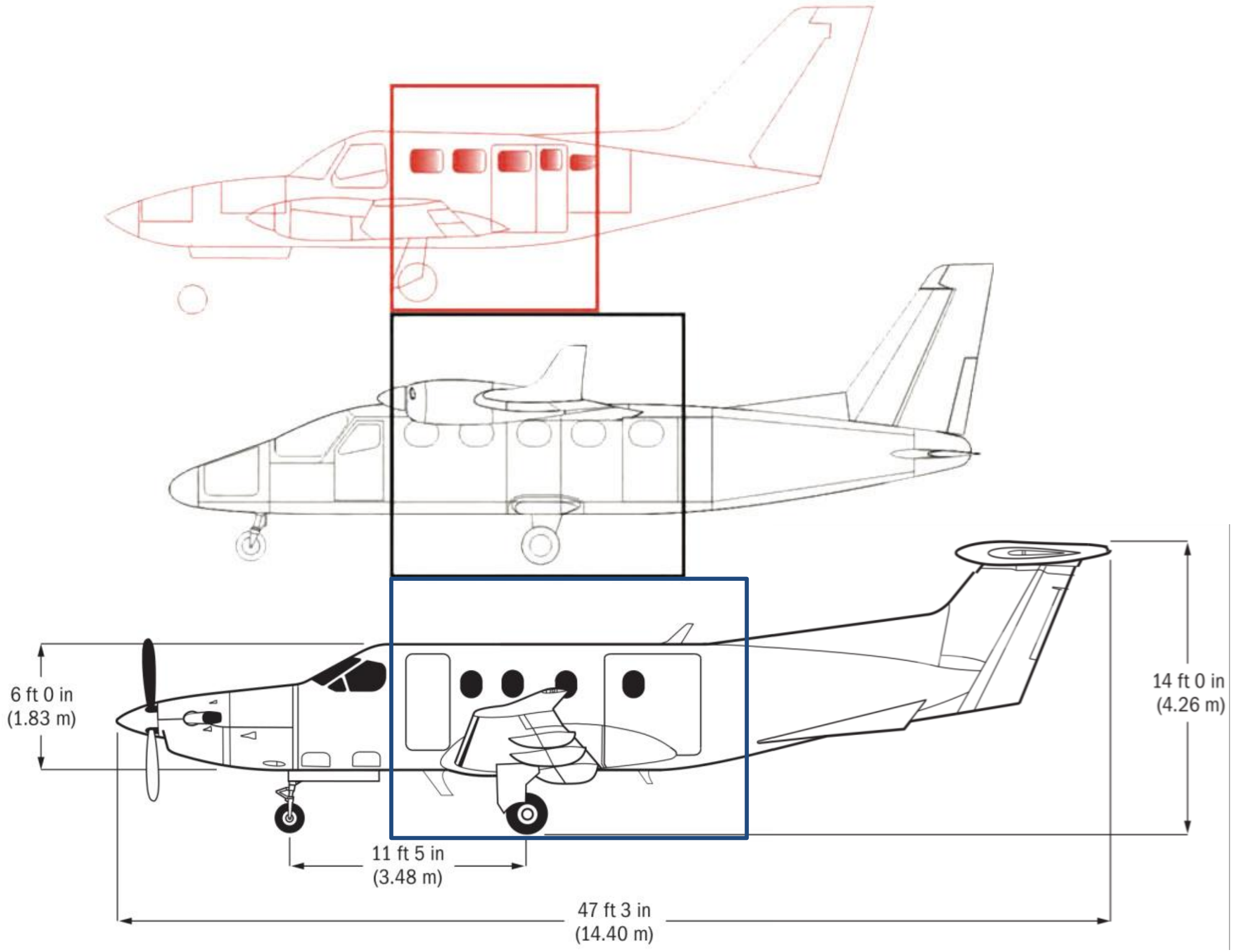
# Comparison of specifications

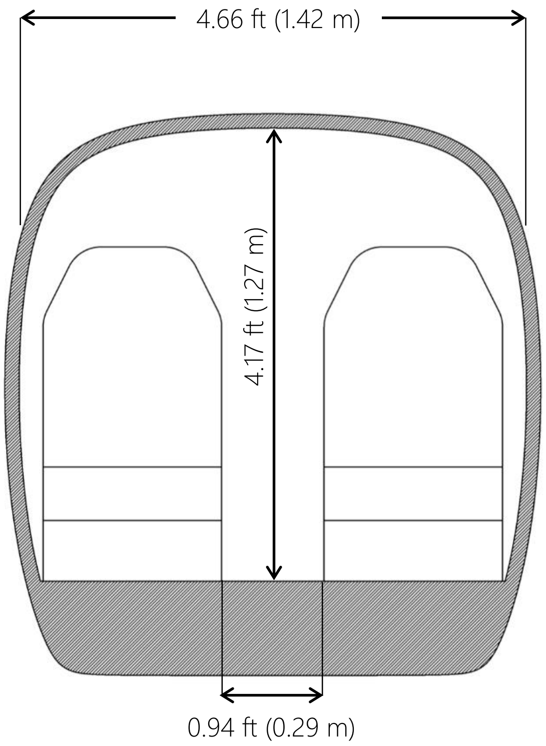
| | Cessna 402C | Tecnam P2012 | Pilatus PC-12 | Advanced concepts |
|---|---|---|---|---|
| Range | 875 nm | 620 nm | 1,845 nm | 400 nm |
| Stall speed (CAS) | 67 kt | 60 kt | 67 kt | 67 kt |
| Takeoff run | 1,763 ft | 1,410 ft | 1,480 ft | 2,000 ft |
| Seats | 10 | 11 | 11 | 11 |
| Engine(s) | TSIO-520 | TEO-540 | PT6A | Varies |
| Total power | 650 hp | 700 hp | 1,200 hp | Varies |
| Retractable gear | ✓ | | ✓ | ✓ |
| Max cruise speed | 194 KTAS | 210 KTAS | 285 KTAS | 180-325 KTAS |
| Pressurized | | | ✓ | Varies |

Cessna 402

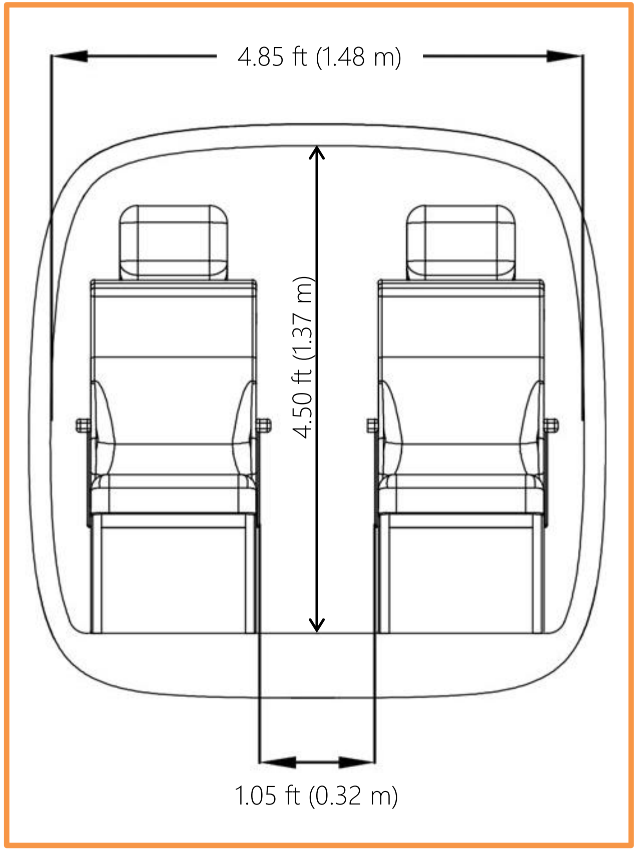
Tecnam P2012

Pilatus PC-12

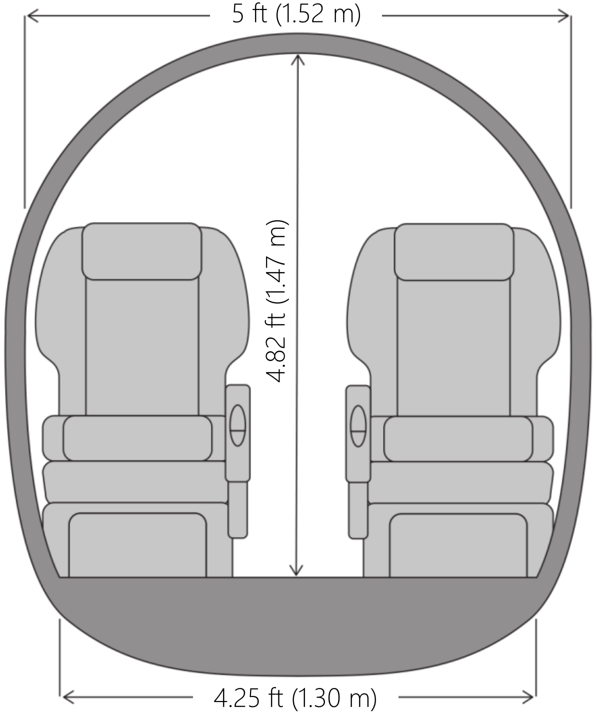





Cessna 402



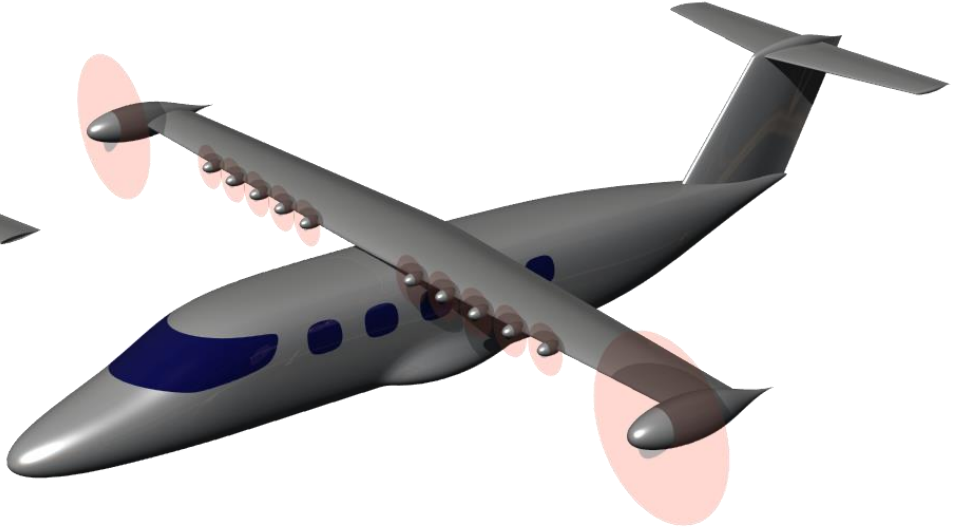

Tecnam P2012




Pilatus PC-12

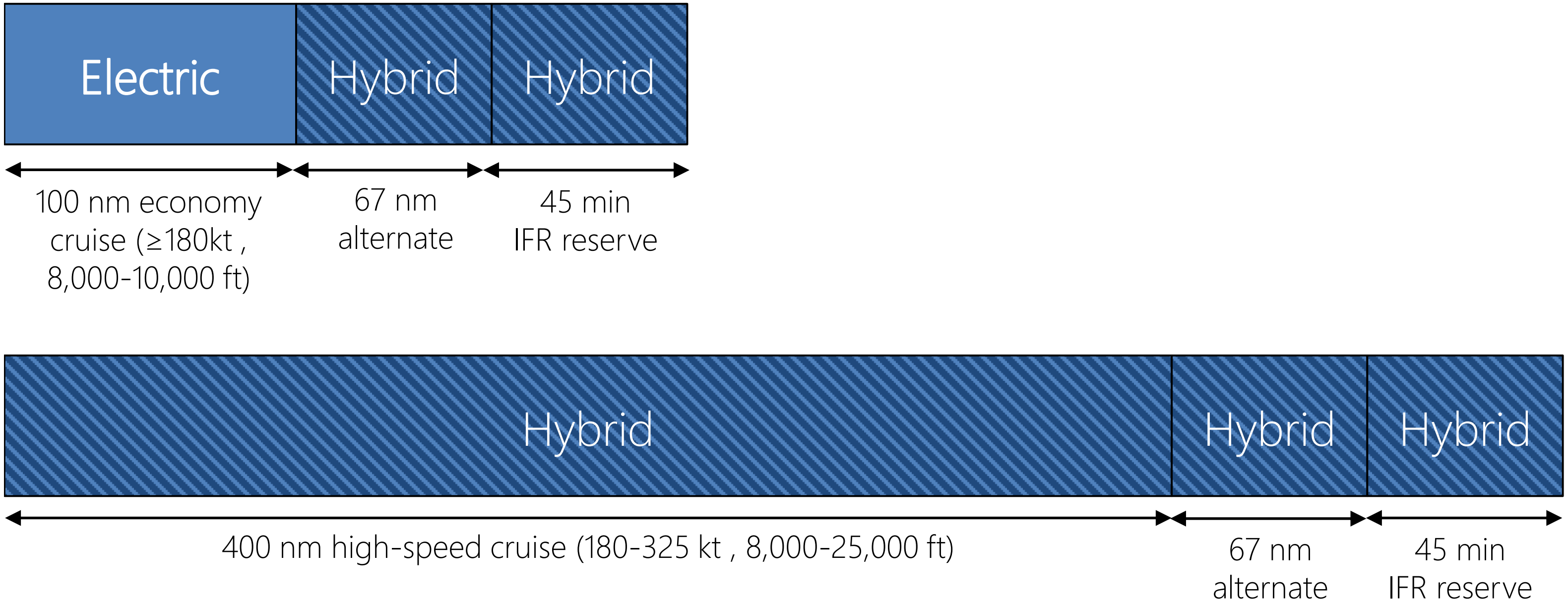
# Advanced design configurations

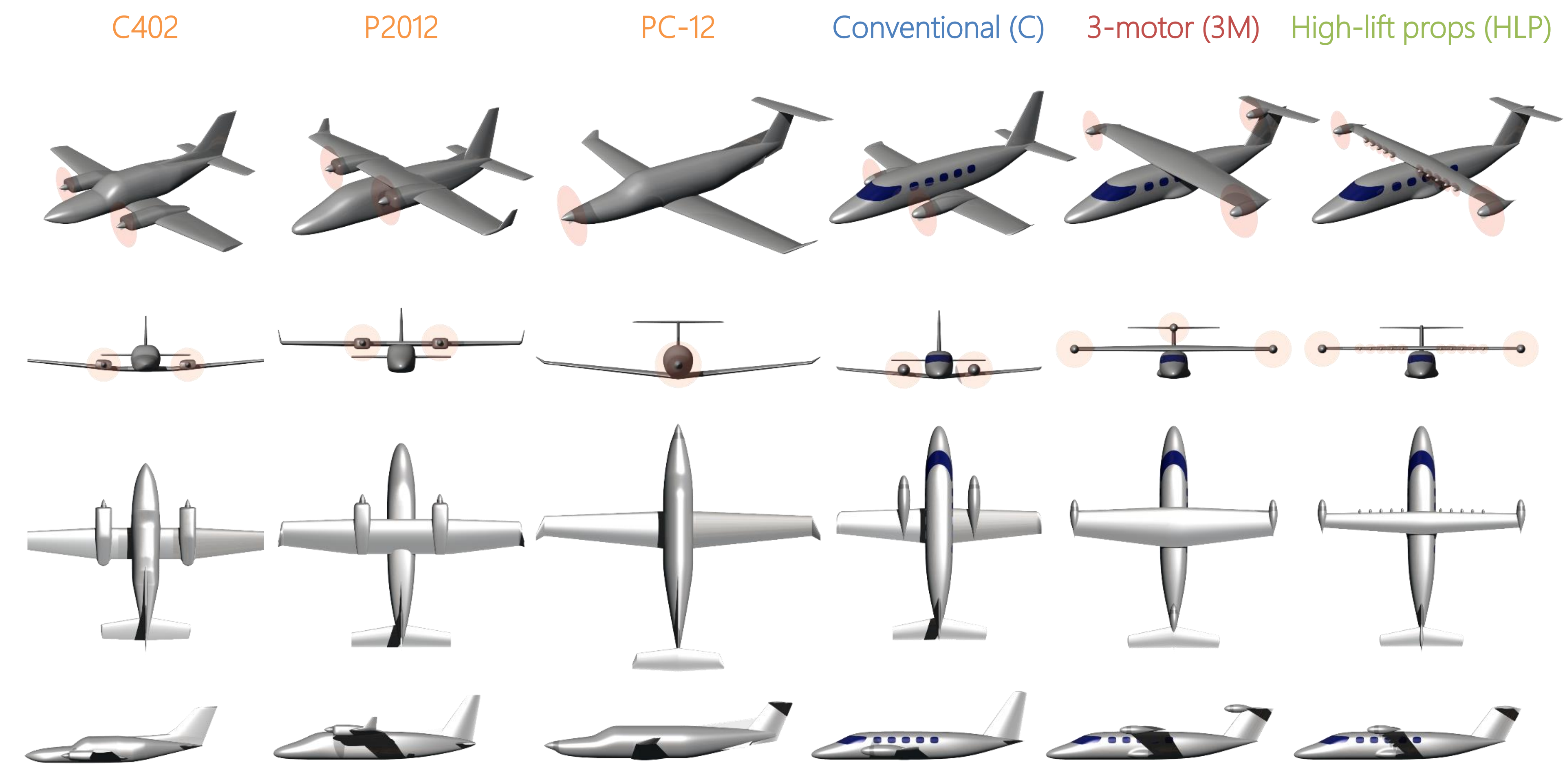
Turbodiesels or turboprops



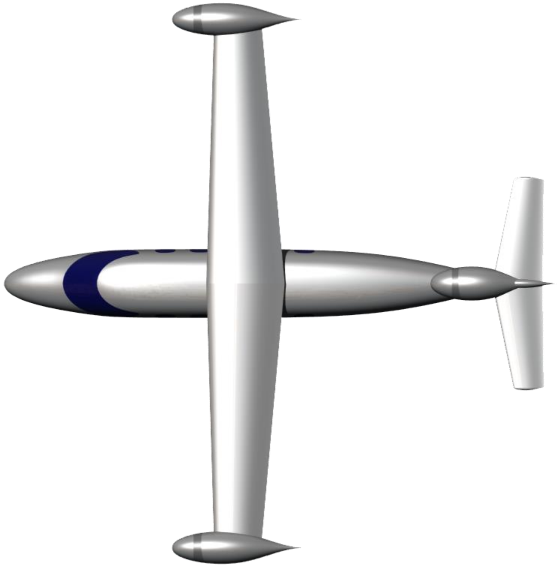
Electric motors with turbodiesel or turbine range extender

# Mission descriptions

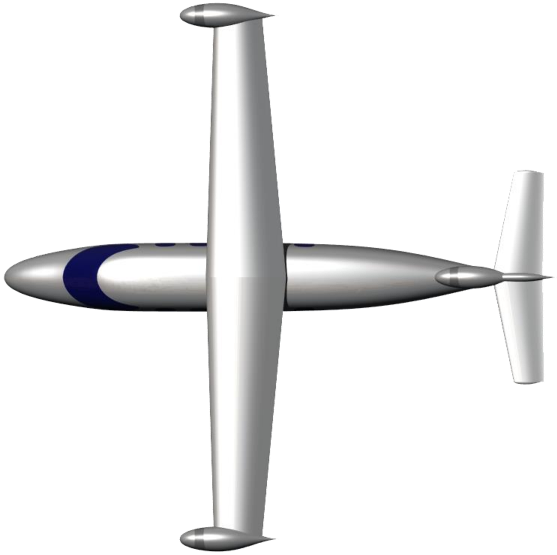



C402
P2012
PC-12
Conventional (C)
3-motor (3M)
High-lift props (HLP)

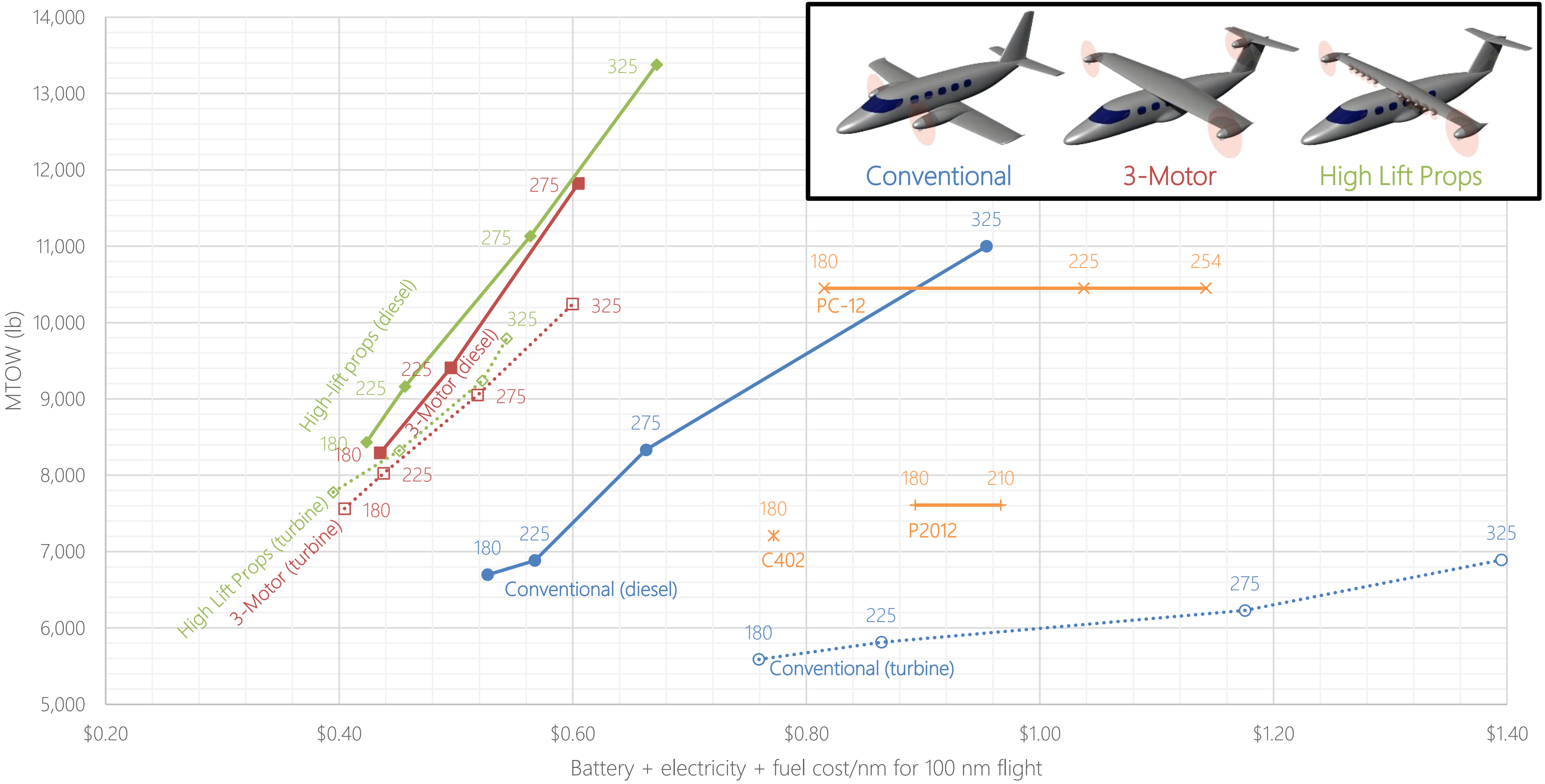
Lowest battery+electricity cost



Lowest gross weight

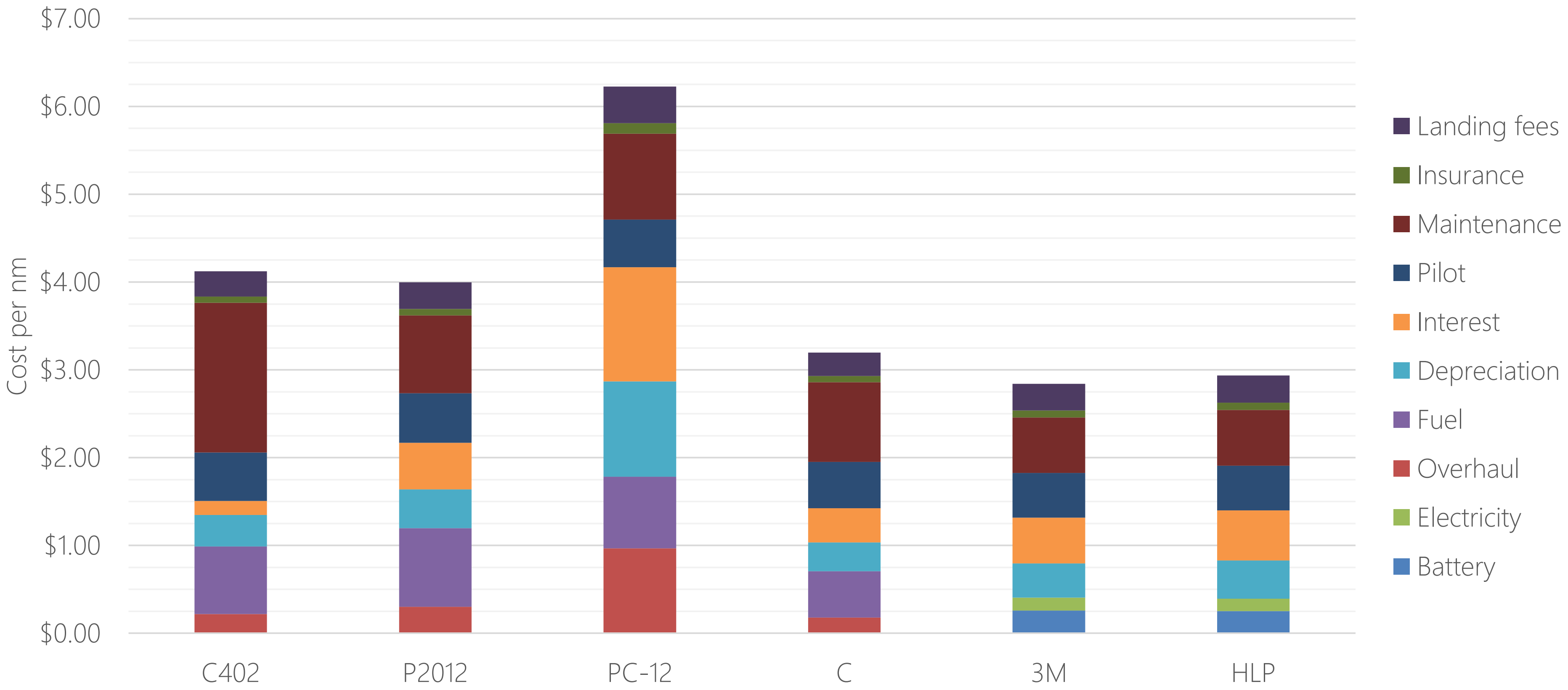


Lowest total cost

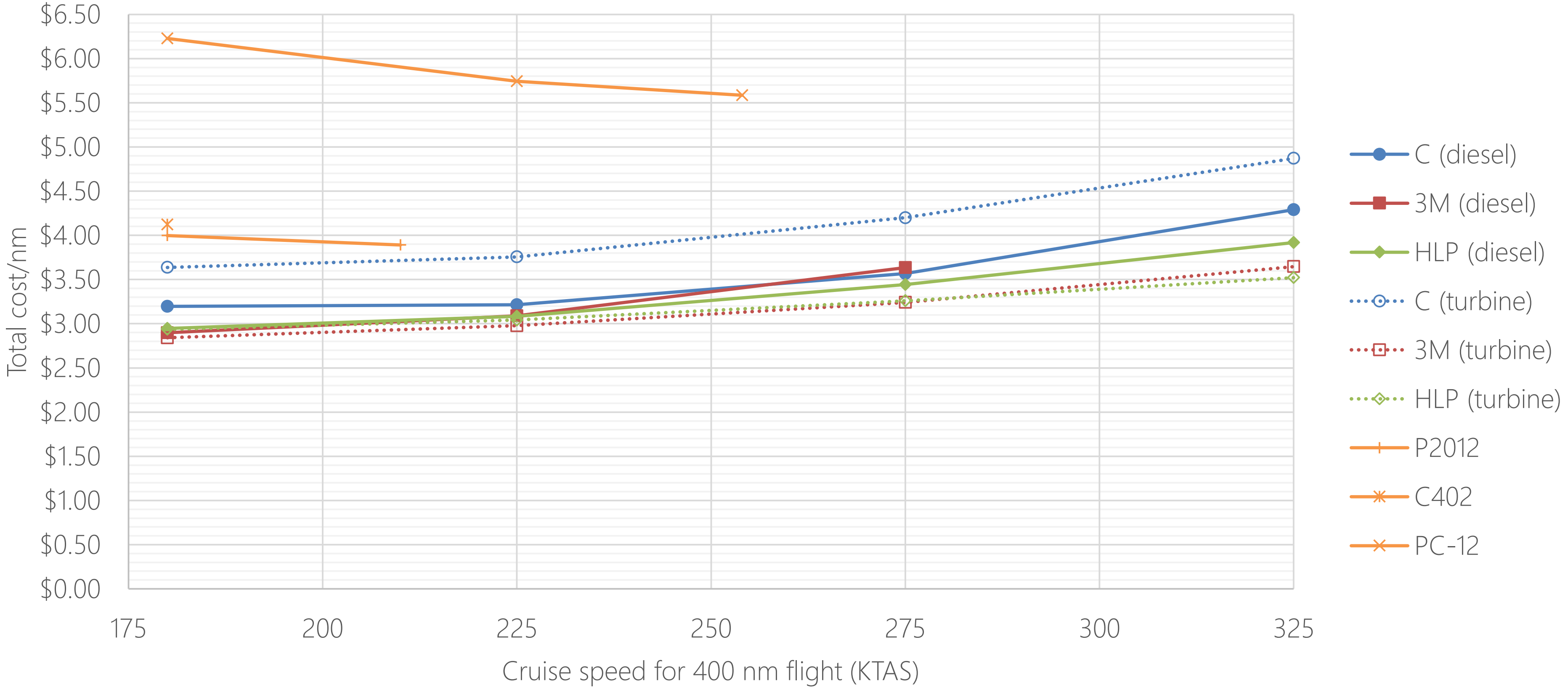


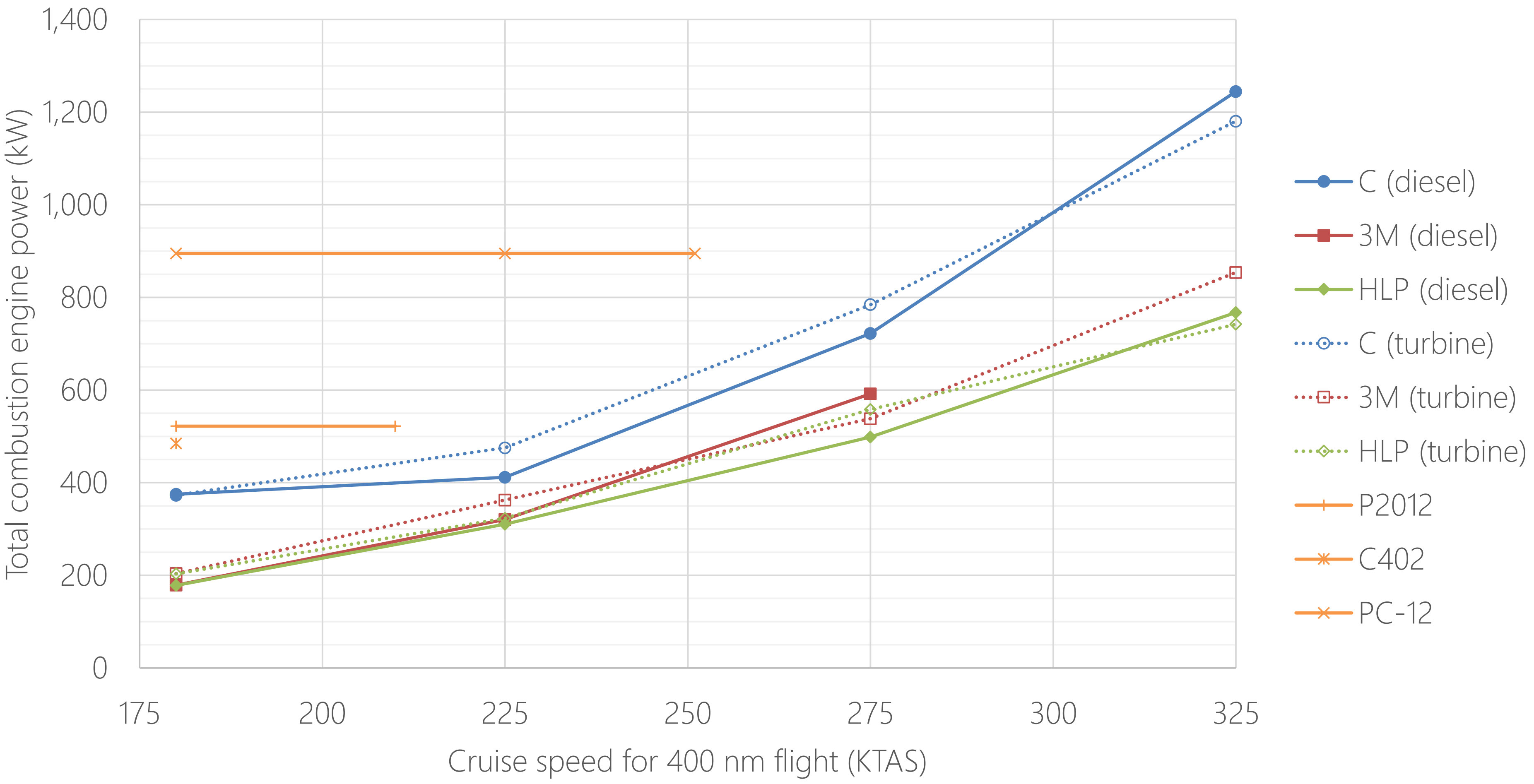
Conventional
3-Motor
High Lift Props
MTOW (lb)
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
$0.20
$0.40
$0.60
$0.80
$1.00
$1.20
$1.40
Battery + electricity + fuel cost/nm for 100 nm flight
High-lift props (diesel)
3-Motor (diesel)
High Lift Props (turbine)
3-Motor (turbine)
Conventional (diesel)
Conventional (turbine)
PC-12
P2012
C402
180
225
254
210
275
325

# Operating costs for 180 kt, 100 nm flight

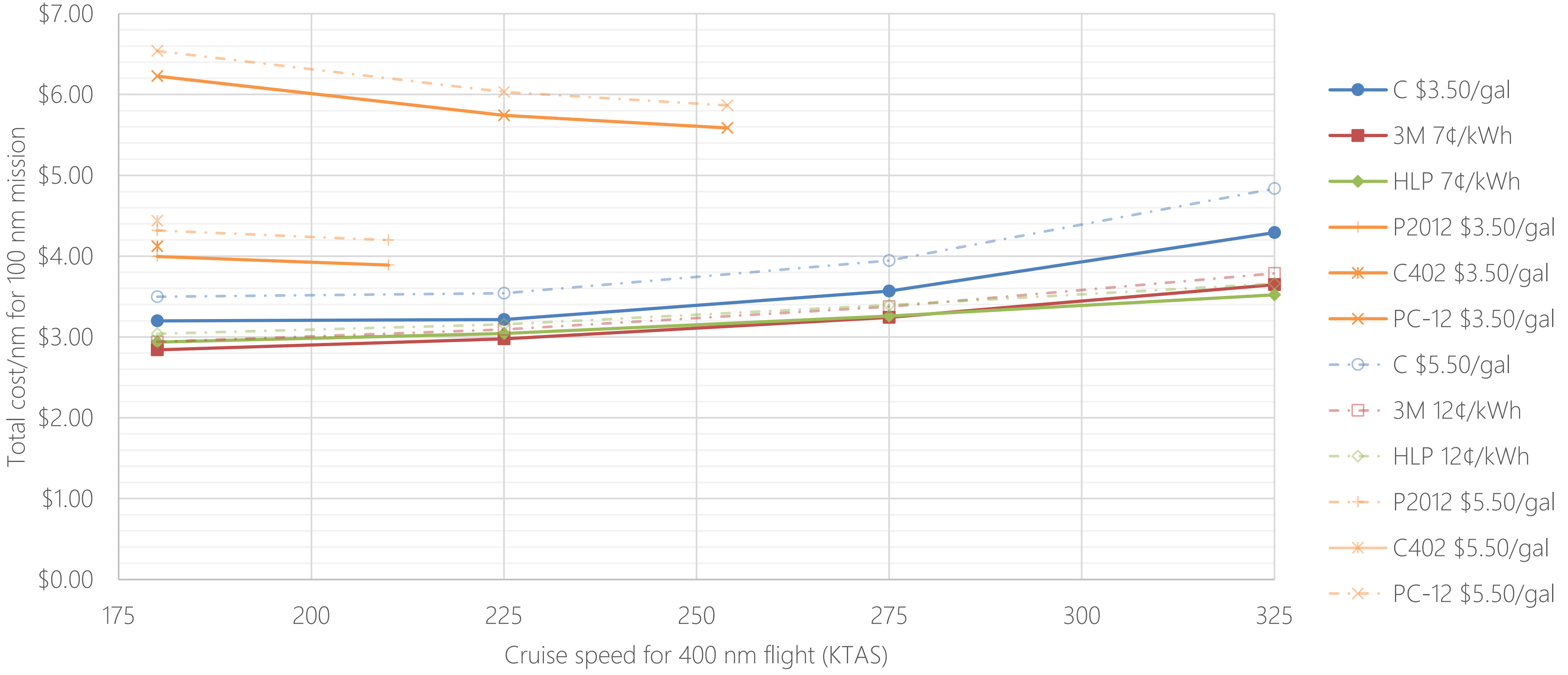


# 100 nm flight costs




Total combustion engine power (kW)
0
200
400
600
800
1,000
1,200
1,400
175
200
225
250
275
300
325
Cruise speed for 400 nm flight (KTAS)
C (diesel)
3M (diesel)
HLP (diesel)
C (turbine)
3M (turbine)
HLP (turbine)
P2012
C402
PC-12

# Energy cost sensitivity

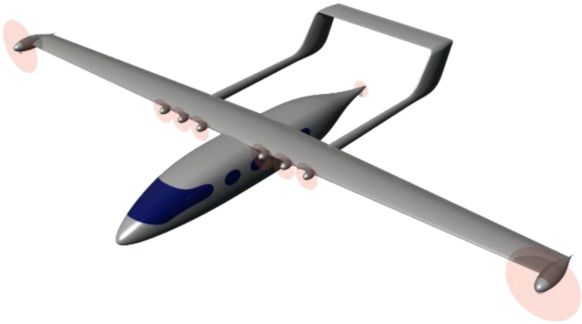


# Acknowledgements

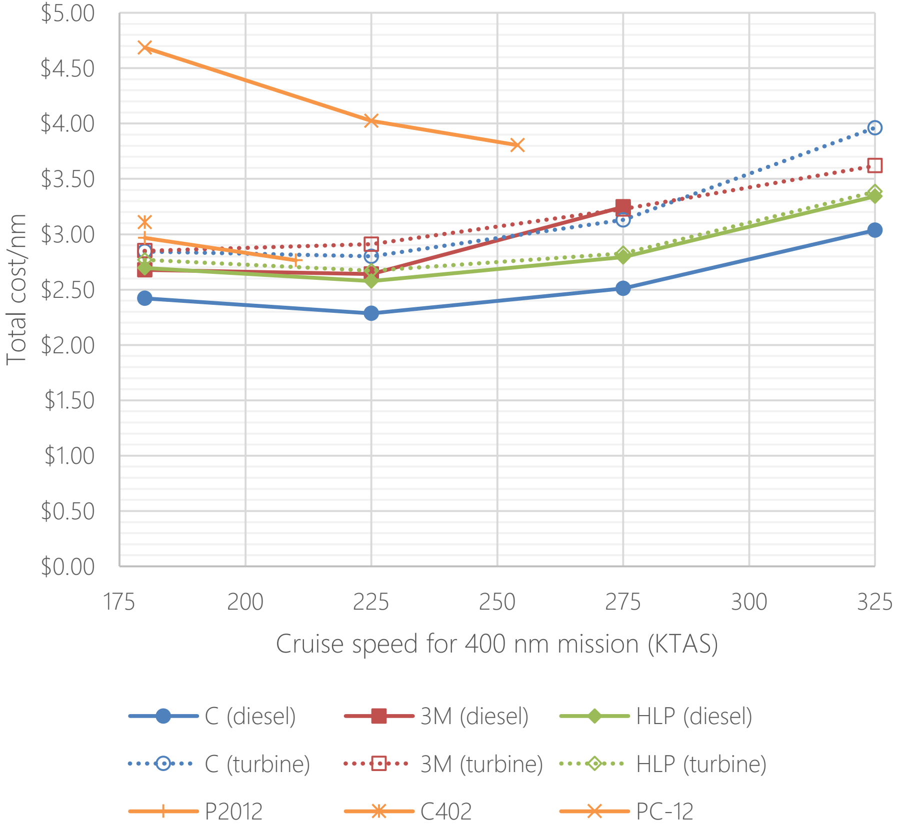

- NASA Langley (Dr. Nick Borer, Bill Fredericks, Ken Goodrich, Mark Moore, Michael Patterson)
- Dr. Joachim Grenestedt

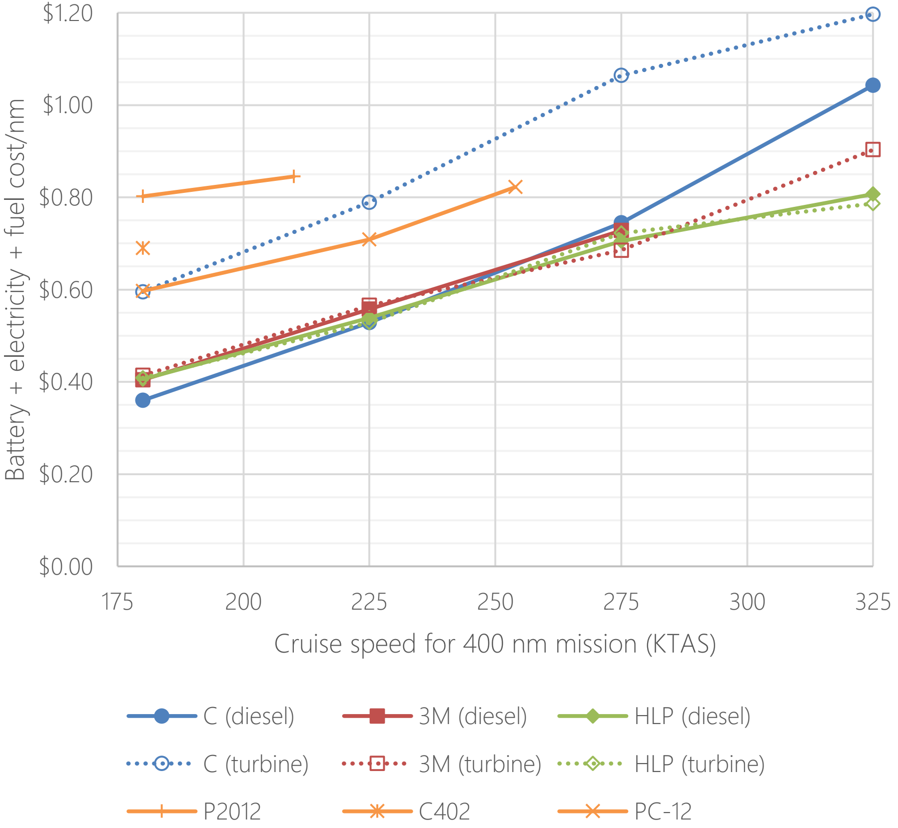
# Future Work

- CFD validation of current designs
- Boundary layer ingestion propeller analysis
- Aeroelastic analysis
- Additional configuration analysis (e.g. twin boom)

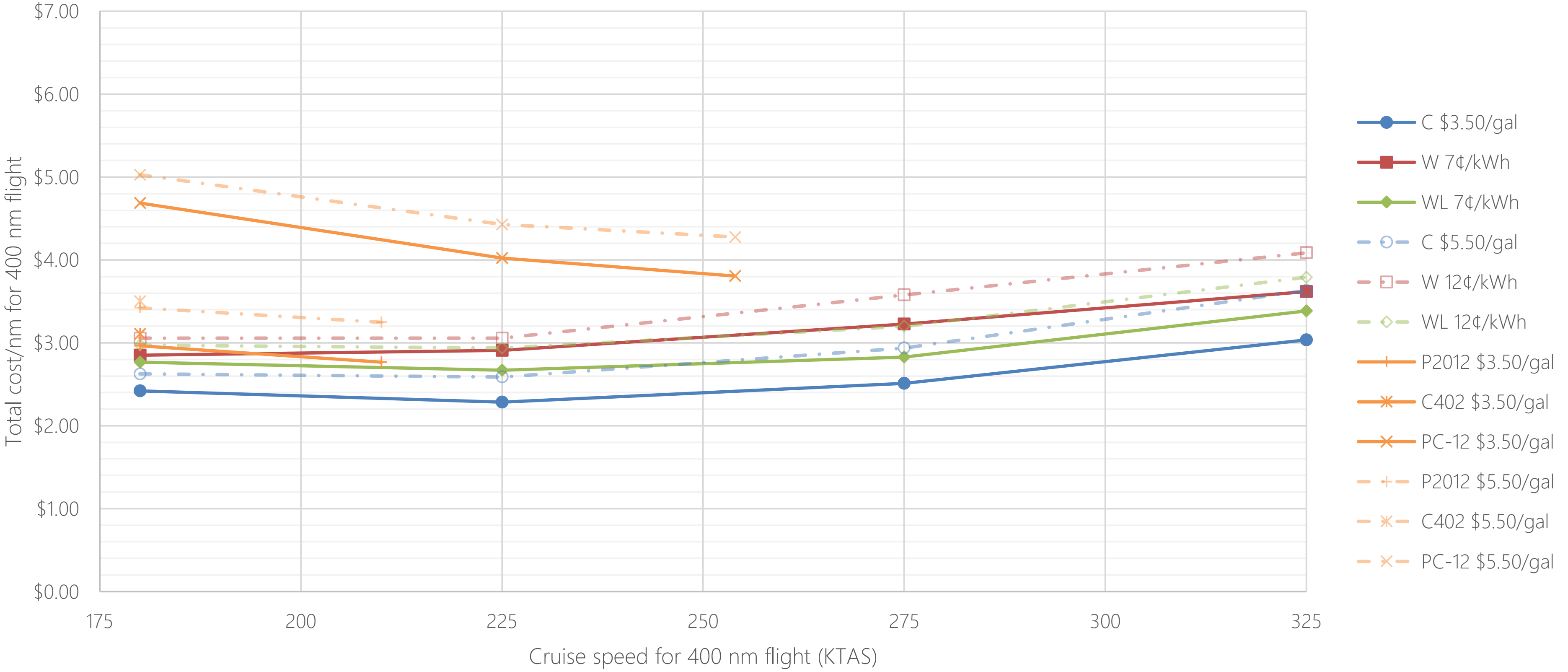


# 400 nm flight costs

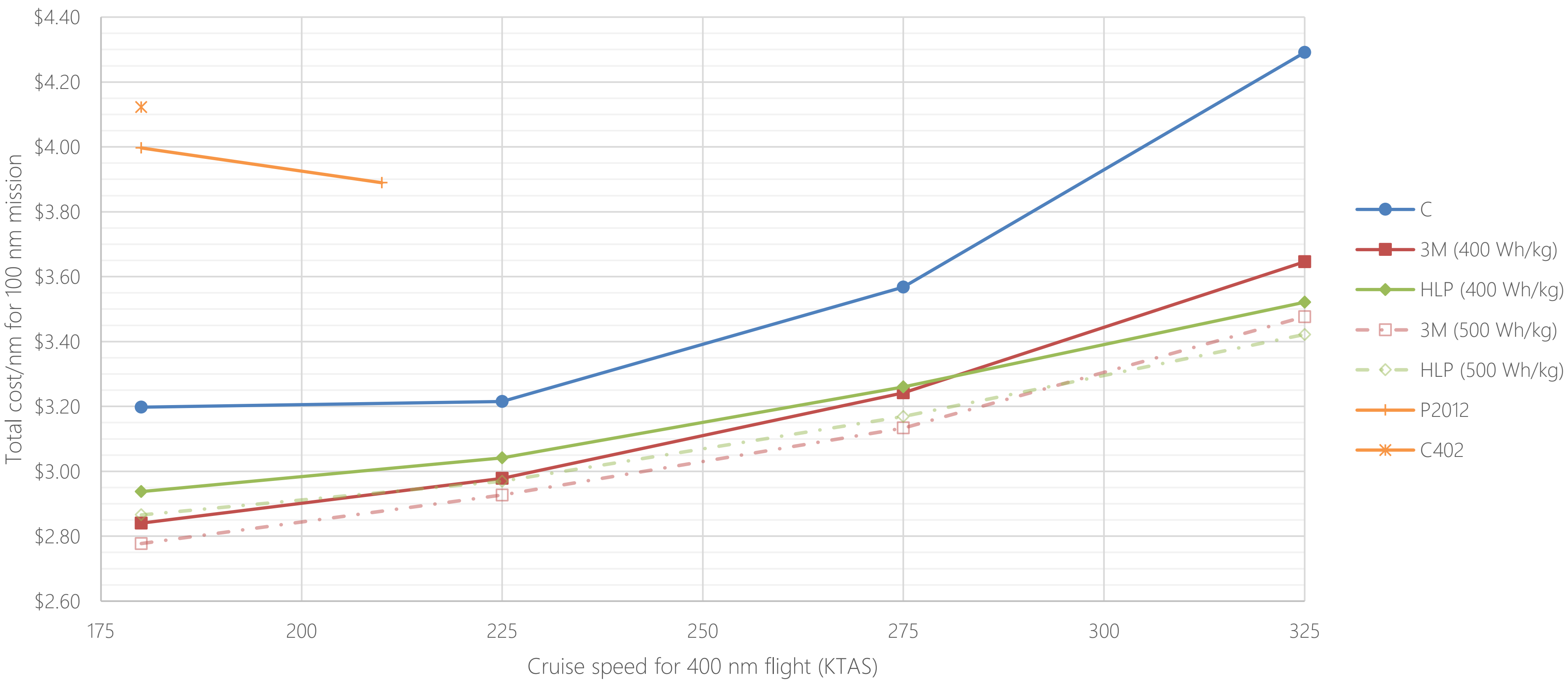


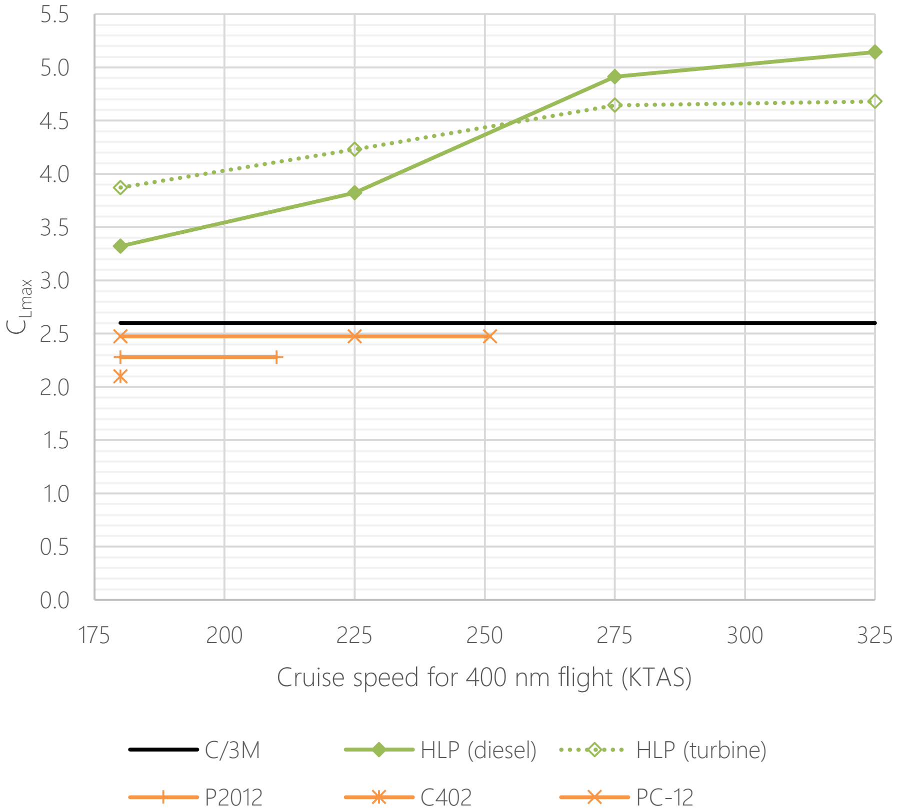
# Energy cost sensitivity for 400 nm flight

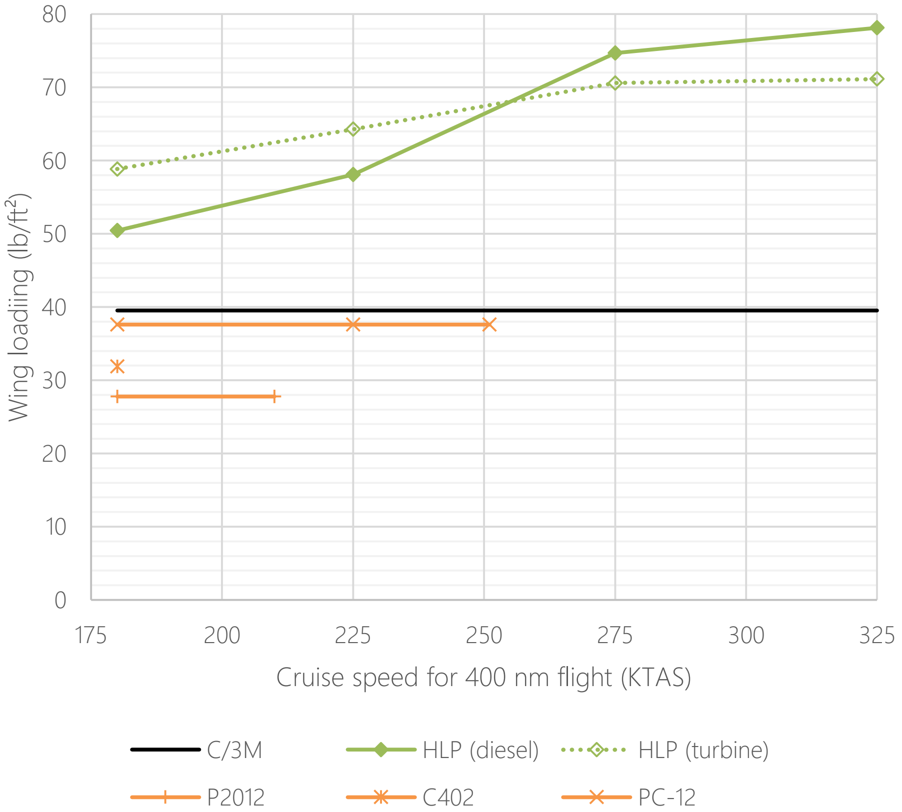


# Specific energy sensitivity



# Effect of high-lift propellers



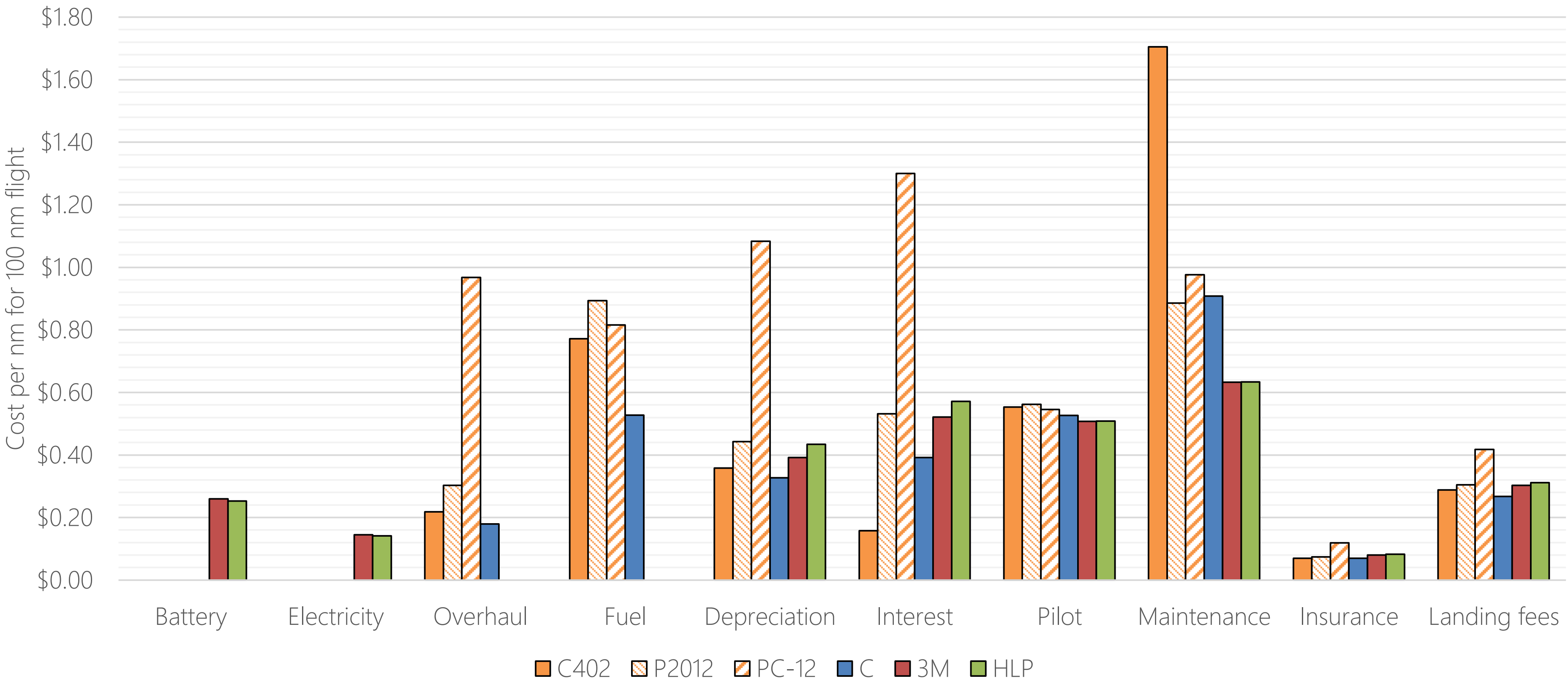
# Engine options for advanced concepts

| | Turbodiesel | Turboprop | Turbine generator (recuperated) |
|---|---|---|---|
| SFC (lb/hp/hr) | 0.36-0.41 | 0.63 | 0.45 |
| TBO | 2,400 hours | 3,600 hours | 6,000 hours |
| Critical altitude | 10,000 ft | Sea level | Sea level |
| Specific power | 0.48 hp/lb | 2.1 hp/lb | 2.0 hp/lb |
| Cost per 100 hp | $39,000 | $56,000 | $56,000 |
| Minimum size | 230 shp | 250 shp | 250 shp |

# Operating cost components

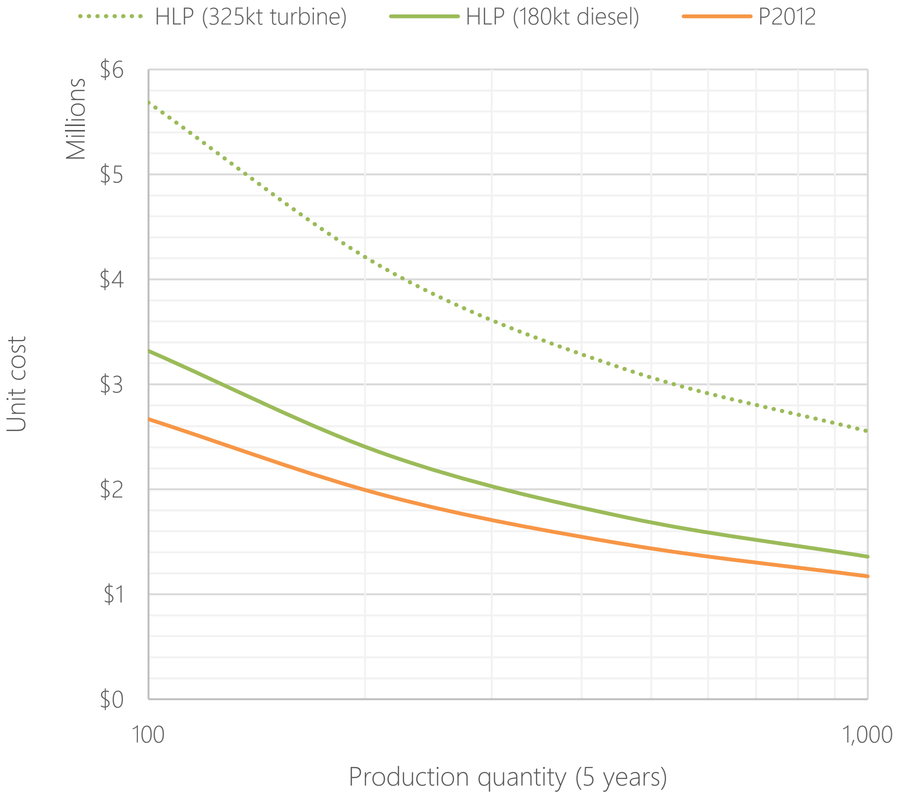
- Battery amortization (2,000 cycles, 20¢/kWh)
- Electricity (industrial rate: 7¢/kW)
- Fuel ($3.50/gal)
- Overhaul reserve
- Depreciation (30,000 hours)
- Interest
- Pilot
- Maintenance
- Insurance
- Landing fees

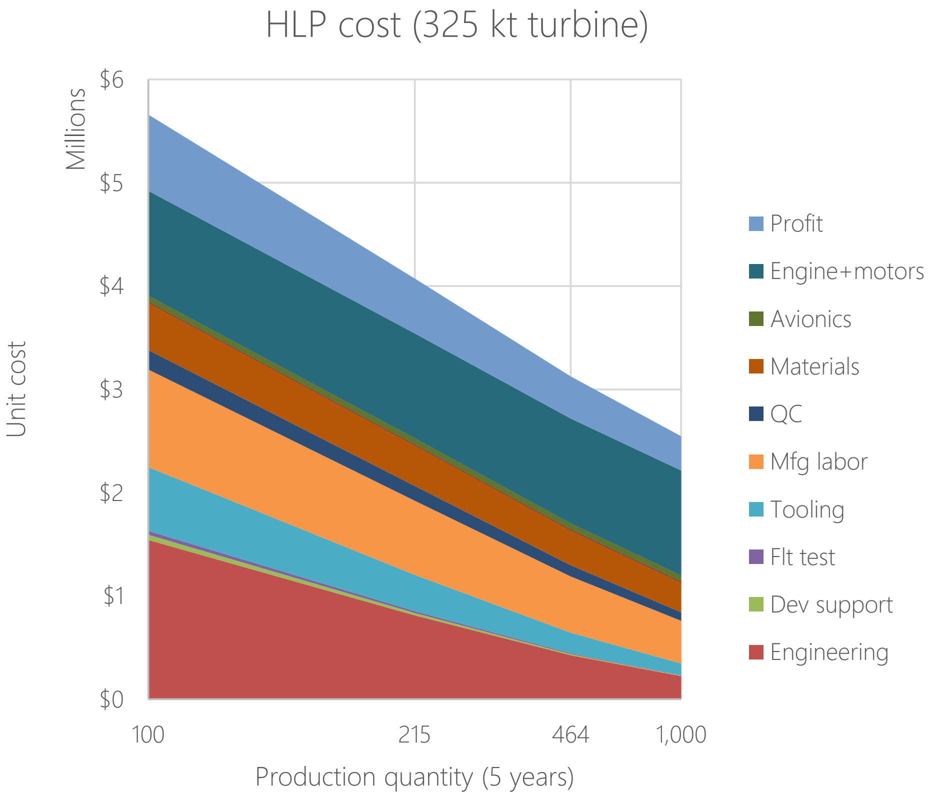
# Operating costs for the 180 kt, 100 nm mission



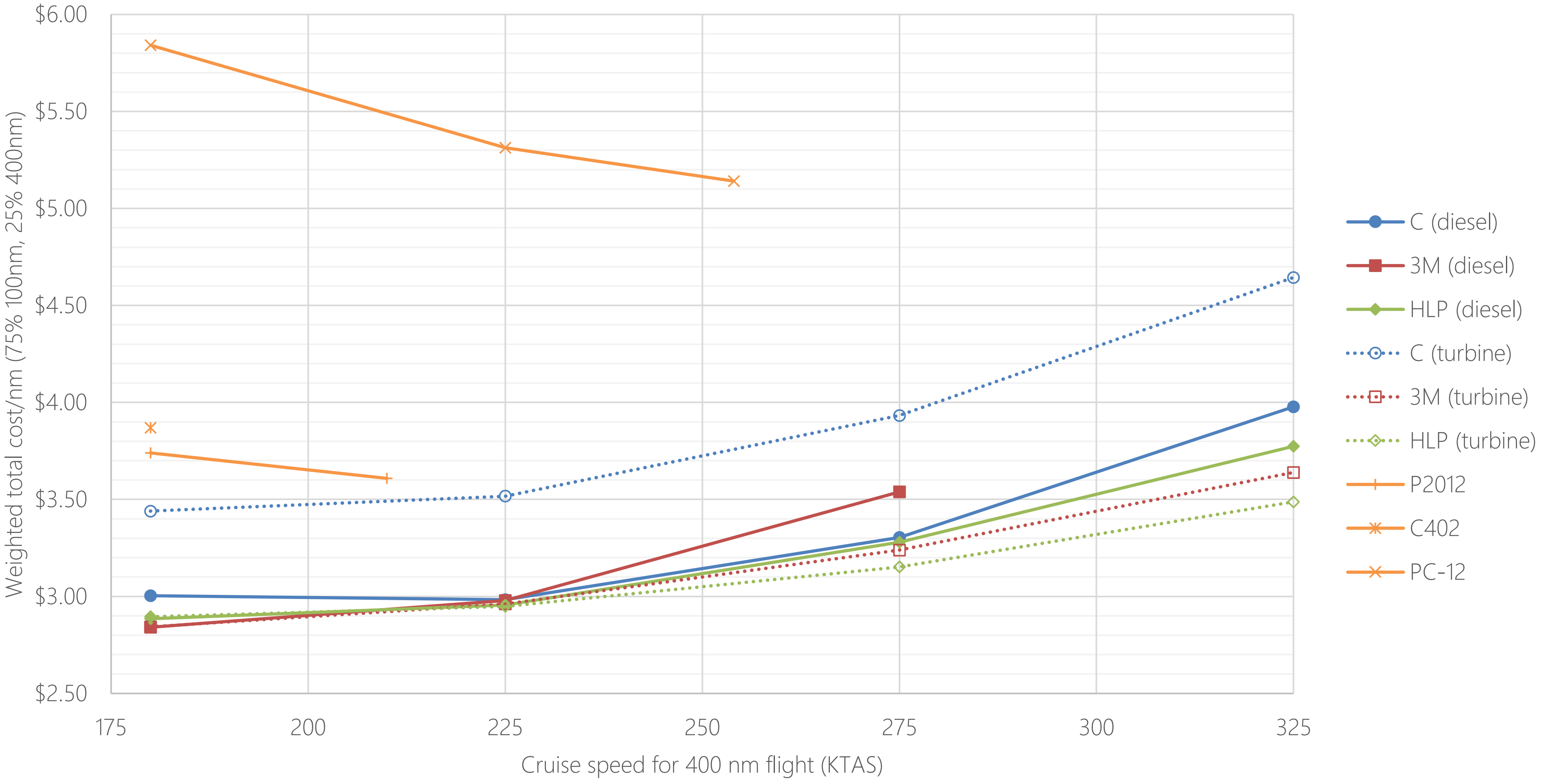

JOBY AVIATION

# Aircraft unit cost model




JOBY AVIATION


$6.00
$5.50
$5.00
$4.50
$4.00
$3.50
$3.00
$2.50
Weighted total cost/nm (75% 100nm, 25% 400nm)
175
200
225
250
275
300
325
Cruise speed for 400 nm flight (KTAS)
C (diesel)
3M (diesel)
HLP (diesel)
C (turbine)
3M (turbine)
HLP (turbine)
P2012
C402
PC-12