Requirements Specification for the Rotary UAV

University of Bristol - AgustaWestland Rotary Wing Design Project 2014
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1. Introduction

The following specification describes the requirements for a new unmanned aerial vehicle (UAV). The vehicle must be equipped to provide cargo transportation, firefighting capability and surveillance functions as required.

The air vehicle must be capable of operating in poor weather, day and night, with particular attention to operation in high winds, in conditions of poor visibility, in sandy or dusty environments and in ice & snow.

The anticipated operations demand extended periods of hovering and low speed manoeuvring over built-up areas. High speed capability is not a specific requirement, but achieving the largest possible range of operations is desirable. Every effort should be made to minimise the noise and the environmental impact of the aircraft.

Rotary UAVs are a relatively new concept and the airworthiness and legislative frameworks for operation of these vehicles in public airspace and over populated areas are not firmly established. It will therefore be necessary to ensure that the aircraft is failsafe to the highest practicable degree. For example, in the event of an engine, or other system malfunction, the air vehicle must be able to maintain separation from buildings and obstacles; manoeuvre to a clear space, which may be some distance away, and land safely. To meet this requirement, the aircraft must either be capable of continued flight following an engine failure, or it must be fitted with a means to sustain flight until a safe landing can be made.

The question of autonomy and/or remote piloting must also be addressed. The aircraft must be capable of transporting cargo independently over pre-defined routes. However, the operator should also be able to pilot the aircraft remotely when a greater degree of flexibility or an emergency intervention is required.

The UAV must have a high level of availability with short turn-around and response times.

2. Background & Philosophy

Unmanned Aerial Vehicles (mostly fixed wing) have been used in military and intelligence theatres for many years. Their success in achieving objectives remotely from human controllers has established these aircraft as indispensable tools for transportation of equipment and supplies, and the delivery of weaponry. More recently, these vehicles are being considered for similar roles in the civilian world. Small rotary UAVs are already in use with model aircraft enthusiasts, for obtaining aerial photography and are being developed for autonomous delivery of goods purchased via the internet. The recent publicity surrounding the plans of Amazon to use UAVs for parcel delivery has drawn sceptical attention to this subject.
A requirement for a larger scale rotary UAV now exists, building on the initial success of small aircraft of this type but with an increased size and load carrying capability to be of significant practical use in various roles.

The factors critical to developing a new product in this role are expected to be:

- **Cost** – the aircraft must be affordable both to purchase and to operate.
- **Operational capability** – the helicopter must be fitted with state-of-the-art surveillance equipment.
- **Availability** – the UAV must have the minimum of “down-time”; it must be reliable and it must be capable of operation in adverse weather; day or night; hot or cold. It must have a fast turn-round time.
- **Response-time** – the time taken to get airborne from a quick-reaction “primed but shut-down” condition and the time to transit to the area of operation are both important.
- **Endurance** – the ability of the aircraft to remain on task for an extended time and the ability to re-task in flight are both vital to mission success.
- **Public acceptability** – manned helicopters operating over built-up areas cause considerable noise nuisance. This has a negative impact on all helicopter operations.
- **Safety** – an accident, especially if it involves injury to members of the public, is totally unacceptable and would be likely to result in legislation to restrict operation over built-up areas.

The next-generation rotary UAV aircraft must find suitable design compromises to address each of these requirements and deliver a vehicle that is acceptable to the general public and civilian airworthiness authorities.

This UAV must operate in both urban and rural locations, in hot as well as freezing conditions, in daylight and in full darkness. It must be reliable and easy to operate in climatic conditions that vary from desert, where sand-filters and erosion-shields may be required; to arctic climes where icing and low light levels may present significant challenges. Consideration must be given both to the aircraft’s task-specific role-fit items and to the operational fit required to fly safely in a wide-range of customer locations.

In advance of any agreed airworthiness requirements for this type of aircraft, the UAV will be designed to comply, where relevant, with the civil airworthiness requirements of the European Aviation Safety Agency and with the operational regulations expressed in JAR-OPS3. Care will be required to assess what are the relevant and important requirements and regulations for the aircraft as not all of the existing rules will or should apply. Choices and decisions in this regard should be explained and justified.
3. Rotary UAV System Requirements

3.1 General Operational Requirements

The Rotary UAV must be able to operate world-wide in hostile environments and extremes of atmospheric and weather conditions. Specifically, the operational envelope must permit the following:

- Operation within the temperature range -40°C to +50°C
- Operation up to a pressure altitude of 15,000ft (4600 m)
- Operation in day, night and all adverse weather conditions
- Operation in ice, snow, dust and general IMC conditions
- Operation in controlled and uncontrolled airspace
- Operation from restricted sites and landing pads
- Operation from sloping sites with up to 12° inclination

3.1.1 General Loading Considerations

For the defined mission profiles the aircraft must be fitted with role specific equipment as required. Where role equipment is specified, carriage is mandatory and suitable space provisions must be allowed. The location of this equipment (for the purposes of weight and balance analysis) can be taken as being directly beneath the rotor(s) centreline at floor level.

3.1.2 Aircraft Configuration and Sizing Considerations

The critical factor affecting the selected aircraft configuration and sizing is to be able to complete the key mission profile carrying the required payload. No explicit constraint is placed on maximum aircraft length (rotors turning); however, in practice this parameter will limit the areas within which safe operations may be performed and therefore should be designed to be as low as reasonably possible (ALARP).

3.1.3 Key Missions

The aircraft must be sized to perform the defined rotary UAV missions - surveillance, cargo transportation and firefighting.

The UAV must be able to cope safely with a single powertrain failure at the most critical point in the mission (for example whilst hovering above a built-up area) and make a safe landing. The landing does not necessarily have to be at an approved helicopter operating site. The specific performance requirements that are imposed to ensure the necessary engine failure compliance are expressed in section 3.1.8. of this specification.

On return to its operating base at the completion of any mission the aircraft must have sufficient energy reserves to stay airborne at 300m (1,000ft) for a further ten
minutes at the best range speed to allow for a ground based emergency and the diversion to an alternative landing site.

Where not stated here the mission must be conducted in compliance with the relevant performance rules of JAR-OPS 3 (subparts G and H).

3.1.3.1 Mission: Surveillance

The ambient temperature for this mission is ISA +30°C. Zero wind. The operating base and the scene of operations are both at 3000 ft above mean sea level.

The aircraft must take-off from the quick-reaction shut-down condition within 5 minutes and transit the 15nm to the scene of operations within a further 8 minutes (allow 1 minute for the take-off hover in ground effect followed by 7 minutes for the transit). The transit is to be flown at 1,000 ft above ground level (4,000 ft pressure altitude).

The UAV descends en-route to arrive at the scene at 500 ft above ground level (3,500 pressure altitude). The aircraft then operates for 9 periods consisting of 10 minutes loiter at the minimum power speed, followed by 10 minutes of hover (zero wind).

After remaining for a total of 3 hours on-station, the UAV returns to the operating base at the best range speed, at 1,000 ft above ground level (4,000 ft pressure altitude).

On arrival at the operating base the helicopter must have sufficient fuel to fly for a further 10 minutes at the best range speed and then land (1 minute hover in ground effect).
Outbound leg

Take-off: hover (in ground effect)
   Power: as allowed by the engine and transmission rating structure
   Time: 1 minute
Climb to 1,000 ft above ground level (4,000 ft pressure altitude):
   Power: as allowed by the engine and transmission rating structure
   Time: dependent on the rate of climb
   Average speed during climb: 100kts
   Distance: dependent on the rate of climb
Cruise to operational area:
   Power: as required up to maximum continuous power
   Speed: sufficient to achieve the specified leg duration
   Distance: 15 nm, less the distance travelled in the climb and descent phases
Descent to on-station;
   Power: no more than 50% maximum continuous power or,
   Descent rate: 1,000ft/min maximum
   Time: as required
   Average speed during descent: 100kts
   Distance: dependent on the rate of descent

On-station

Loiter at 500 ft above ground level (3,500 ft pressure altitude) at the best endurance speed:
   Power: no more than maximum continuous power
   Time: 10 mins

Hover at 500 ft above ground level (3,500 ft pressure altitude), zero wind.
   Power: as allowed by the engine and transmission rating structure
   Time: 10 mins

Repeat the above loiter-and-hover sequence to give a total of 9 loiter-and-hover sequences; for a total time-on-station of 3 hours.

Return leg

Climb to 1,000 ft above ground level (4,000 ft pressure altitude):
   Power: as allowed by the engine and transmission rating structure
   Time: as required
   Average speed during climb: 100kts
   Distance: dependent on rate of climb
Cruise to operating base:
   Power: as required up to maximum continuous power
   Speed: best range speed
   Distance: 15 nm, less the distance travelled in the climb and descent phases
Descent to operating base:
  Power: no more than 50% maximum continuous power or,
  Descent rate: 1,000ft/min maximum
  Time: as required
  Average speed during descent: 100kts
  Distance: dependent on rate of descent

Landing: hover (in ground effect)
  Power: as allowed by the engine and transmission rating structure
  Time: 1 minute

Prior to landing there must be energy reserves available to permit an additional ten minutes (10mins) diversionary repositioning leg, flown at 1,000ft above ground level, at the best range speed with all engines operating. Plus the minimum landing fuel allowance.

3.1.3.2  Mission: Payload Delivery

The ambient temperature for this mission is ISA +30°C. Zero wind. The operating base and the delivery location are both at 3000 ft above mean sea level.

The aircraft must carry a 500kg payload in the form of a loaded LD2 Unit Load Device (ULD) over a distance of 460 km within a time limit of 120 minutes. Take-off includes a 1 minute hover in ground effect. The transit is to be flown at 1,000 ft above ground level (4,000 ft pressure altitude).

On arrival at the delivery point the aircraft must have sufficient energy reserves to fly for a further 10 minutes at the best range speed and then land (1 minute hover in ground effect).
Outbound leg

Take-off: hover (in ground effect)
   Power: as allowed by the engine and transmission rating structure
   Time: 1 minute

Climb to 1,000 ft above ground level (4,000 ft pressure altitude):
   Power: as allowed by the engine and transmission rating structure
   Time: dependent on the rate of climb
   Average speed during climb: 80kts
   Distance: dependent on the rate of climb

Cruise:
   Power: as required up to maximum continuous power
   Speed: sufficient to achieve the specified leg duration
   Distance: 248 nm, less the distance travelled in the climb and descent phases

Descent to delivery point:
   Power: no more than 50% maximum continuous power or,
   Descent rate: 1,000ft/min maximum
   Time: as required
   Average speed during descent: 80kts
   Distance: dependent on rate of descent

Landing: hover (in ground effect)
   Power: as allowed by the engine and transmission rating structure
   Time: 1 minute

Prior to landing there must be energy reserves available to permit an additional ten minutes (10 mins) diversionary repositioning leg, flown at 1,000ft above ground level, at the best range speed with all engines operating. Plus any applicable minimum landing fuel/energy allowance.

3.1.3.3 Mission: Firefighting

The aircraft, carrying a suitable uptake and delivery method for a water load of 500kg must take-off from an operating base located at 3000ft PA and transit to an operating zone (fire traffic area) located at 15nm distance and 6000ft elevation. The procedure is then to take on 500 litres of water from a suitable reservoir, transit to the fire at 5nm distance, drop the load then return 5nm to the reservoir. This profile is repeated to give a minimum on-station duration of 75 minutes (desirable 90 minutes).

The ambient temperature for this mission is ISA +20°C.

Essential Role Equipment

The aircraft will be configured with an appropriate water uptake / delivery device (e.g. bambi bucket/water tanks) at the discretion of the design team (structural attachment provisions, empty mass and CG impact must be accounted for).
Profile

Engine warm-up – 2 minutes at ground idle.
Take-off - free air hover (out of ground effect) for 1 minute (NB – no payload)
Cruise-climb to 6000ft
  Power; up to maximum continuous power
  Average speed during leg = best range speed
  Distance = 15nm

On-station Operations¹
  Take-on 500kg payload from OGE hover (minimum 1 minute duration)
  5nm transit to fire zone at a maximum airspeed of 80KTAS
  Position for and execute bombing run – 3 minutes at maximum endurance speed
  Drop payload and return 5nm at 100KTAS to reservoir to reload.
  Repeat for a minimum of 75 minutes (desirable 90 minutes).

Return to helibase
  Average speed during leg = best range speed
  Distance = 15nm

Landing; free air hover (OGE) for 1 minute at 3000ft ISA+20
Fuel reserve of 20 minutes at best endurance speed.

3.1.4 Airspeed

The rotary UAV must be capable of a maximum level cruise speed of 260kph (140kts). This speed must be achievable at 90% of maximum all-up-weight (MAUW) and at a density altitude of 1500m.

A level cruise speed of 250kph (135kts) must be possible at an altitude of 2000m (6500ft) in ISA-25°C conditions.

3.1.5 Altitude

The rotary UAV, configured for the surveillance mission, must be capable of flying the mission from an operating base that is 9,000 ft above mean sea level on an ISA+15°C day; but with the on-station requirement reduced to 40 minutes (2 loiter-hover sequences).

The aircraft, at the AUM at the start of the first on-station hover of the high altitude mission profile, must be capable of achieving a level flight true airspeed of at least 150kph (80kts) for a minimum of 3 minutes when operating with one engine failed at 9,500ft pressure altitude on an ISA+15°C day.

3.1.6 Hover

¹ NB for modelling purposes it is sufficient to consider fuel consumption at 100KTAS but ensuring sufficient power is available to meet the HOGE requirements.
The aircraft must be able to hover out-of-ground effect (OGE) at maximum all up weight (MAUW) at 1000m (3300ft) and ISA+30°C, using an engine and transmission rating appropriate to the key surveillance mission.

The rotary UAV, configured for the surveillance mission and with fuel to hover out-of-ground-effect (OGE) for 40 minutes, must be able to hover (OGE) at 10,500ft and an OAT of +10°C.

3.1.7 Handling
In any of the conditions noted in 3.1.6 the helicopter should be able to maintain directional control for wind speeds up to 45kts with wind directions from ahead to the rear quarter on either side (azimuths 0° to 135° port or starboard).

3.1.8 Inoperable Engine

In the event of an engine failure, the aircraft must be capable of continued flight or a safe landing in a suitable location. For such a new concept aircraft, a landing in the case of an engine failure must be safe for the public or aircraft operators on the ground. Damage to or loss of the aircraft must be a secondary consideration.

Therefore, either a secondary engine or auxiliary power source must be fitted, a controlled power-off landing must be possible, or some other means of bringing the aircraft to the ground in a way that is safe for the general public must be provided. If required, the selection of an auxiliary power source should be based on factors such as, but not limited to, weight, cost, maintenance burden and aircraft performance.

3.1.8.1 Engine Failure En-route or in the Loiter

In the event of an engine failure en-route, it must be possible to establish a safe flight condition without the rotor speed limits being exceeded, or to bring the aircraft to the ground without risk of death or injury to those on the ground.

If a controlled landing is to be made, the aircraft must be provided with either a second engine, or an energy storage device that will allow a safe landing to be performed onto a smooth flat surface at 95% of the maximum take-off weight in ISA+30°C conditions, at terrain elevations up to 1,000m (3,300 ft) above mean sea level. The run-on landing speed should be no greater than 15 knots TAS, and no damage must be caused to the aircraft structure or landing gear. The point of landing shall be at least 3km, and should be at least 5km from the point of engine failure.

3.1.8.2 Engine Failure in the Hover

In the event of an engine failure in the hover, the aircraft must be brought to the ground without risk of death or serious injury to those on the ground. If a formal rejected take-off or flyaway capability is to be provided, the rate of rotor speed decay must be sufficiently slow that the automatic systems can land the UAV, or
transition to forward flight and then land the UAV, without the rotor speed limits being exceeded.

If a controlled landing is to be made, the aircraft must be provided with either a second engine, or an energy storage device that will allow the UAV to transition into forward flight with no more than 300ft height loss. The helicopter must be capable of maintaining height, manoeuvring to avoid obstacles and translating at least 2000m (1.08nm) and then performing a safe landing onto a smooth flat surface at 95% of the maximum take-off weight in ISA+30°C conditions, at terrain elevations up to 1,000m (3,300 ft) above mean sea level. The run-on landing speed should be no greater than 15 knots TAS, and no damage must be caused to the aircraft structure or landing gear.

3.1.9 Flying Qualities
The aircraft should require no unusual or exceptional flying skills when flown by a remote pilot. It should be free of any flight instabilities and have progressive and coherent responses to control inputs. It should be possible to fly the air vehicle, manage the flight systems and navigate when operated by a single remote pilot.

3.1.10 External Noise
The support helicopter shall be compliant with the standing civil noise requirements as defined in ICAO CAN 7.

3.2 Communications & Avionic Systems

3.2.1 User Capability Requirements Overview
At this stage, the aircraft is not required to operate in international civil airspace. Communications may be required between a remote pilot and others, e.g. voice and data exchange with governmental, para-military and military organizations, during its missions, but this capability will be provided by the ground station.

The main communication requirement will be to allow a remote pilot to control the aircraft in circumstances where it is necessary.

The installation, control, and display solutions should enable the use and maintenance of standard, commercially available equipments where possible.

It is also desirable that the systems should be designed for the long term enabling ‘future proofing’ over an anticipated 50 year platform life. This will require consideration of systems architectures and installation approaches to enable the incorporation of future in-service system and equipment updates to be achieved quickly and cost effectively.
3.2.2 Communications, Navigation & Landing

Voice communication from or to the aircraft is not required but the communications and navigation systems must allow for all data transfer necessary for the aircraft to perform the specified missions autonomously or to be fully controlled and flown by a remote pilot.

The aircraft must be equipped with an Emergency Locator Transmitter (ELT) in case of emergency landings or ditching.

3.2.3 Future Proofing

The requirement is to have effective use of a competitive aircraft for up to 30 years. The key element from an avionics perspective is the ability to introduce new technology and available replacement systems and growth capability for next 30 years. It is likely that the avionics will need to be changed fundamentally during this timescale due to the pace of electronics technology migration. The solution must therefore address the need to exploit emerging technologies and allow cost effective updates without major airframe costs or disruption to availability.

3.3 General Attributes

3.3.1 Maintainability

System design, installation and configuration choices should aim to reduce the cost, effort and time associated with maintenance of the system for high aircraft availability and mission capability throughout its whole life. This should include techniques to protect against loss of mission availability by mitigating individual failures and enable rapid maintenance turn-around.

3.3.2 Aircraft Features

The aircraft shall be capable of being equipped to successfully complete the required missions and roles. Aircraft dimensions, space provisions, and equipment stowage capability shall be determined only by these requirements. Due consideration should be given to the suite of equipment required by a surveillance helicopter to carry out the range of possible assignments, such as observation, data and evidence gathering and public address.

3.3.3 Regulations & Basis of Certification

The Rotary UAV will be designed and cleared in accordance with the appropriate civil airworthiness regulations. Major subsystems and equipment such as engines and electrical and avionic equipment must be suitably qualified to compliment the aircraft requirement.

3.3.3.1 Relevant Civil Airworthiness Regulations

Where applicable, the aircraft shall be designed and operated in compliance with the following airworthiness regulations as appropriate –

- Certification Specifications for Small Rotorcraft (CS-27, Amendment 3, 2012)
- Certification Specifications for Large Rotorcraft (CS-29, Amendment 3, 2012)
Specific requirements in the event of engine failure are given in Section 3.1.8.

3.3.2 Design Load Factors & Loading Conditions

As required by the regulations, the following design standards must be achieved:

- A static strength margin (ultimate strength factor) of 1.5 must be demonstrated for components subject to the following loads;

- The aircraft must be able to sustain normal accelerations between +3.5g and -0.5g. Pitch accelerations of up to 0.5rads/sec$^2$, consistent with limit manoeuvring, must be simultaneously considered.

- The aircraft must be able to sustain the pressure loadings associated with flight speeds 21% greater than the maximum equivalent airspeed permitted in cruise. These pressure loadings must reflect the extremes of the aircraft pitch and yaw attitude permitted at maximum cruising speed.

3.3.4 Design Fatigue Life

The airframe is expected to have a fatigue life of 15,000 flight hours or 10,000 landings. The use of On-Condition monitoring techniques to supplement this must not place an undue maintenance burden on the operation of the aircraft.

The rotor blades must have a fatigue life of at least 10,000 flight hours.

The mechanical components of the rotors should also have a target fatigue life of 10,000 flight hours.

All other mechanical components subject to fatigue loading and wear should be designed to achieve a fatigue life of at least 5000 flight hours and a Time Between Overhauls (TBO) of at least 1000 flight hours. General maintenance intervals should be at least 200 flight hours.

3.3.5 Vibration

The overall vertical vibration level in the aircraft, should not exceed 0.1g in order to permit unimpaired use of video surveillance equipment.

3.3.6 Bird Strike and Debris Impact

Consistent with the requirements of the regulations, the following environmental and impact hazards must be accommodated;

- The aircraft structure and rotors should be able to sustain (without catastrophic damage) a direct strike with a 1.5kg bird when the aircraft is at its highest permitted absolute cruise speed.
• The airframe structure, intakes, cowlings, drive shaft covers, aerodynamic surfaces and rotor components should be able to withstand contact with hard debris such as hail up to an energy level of 50 joules without failure or disruption.

• Components such as rotor blades should be able to withstand the abrasion of ash, grit, dust and rain as specified.

3.3.7 Health and Usage Monitoring
Provision should be made to allow continuous monitoring of the helicopter usage and the critical loadings and degradation of its systems (including major mechanical components and avionics) to determine maintenance needs and allow improved management of fatigue life.

Knowledge of past operational usage and the recognition of system derangements, together with knowledge of intended operational usage provide the ability to plan for timely maintenance action or mitigating actions to achieve the best operational outcome safely.

Algorithms and additional measuring regimes to recognise system changes that might indicate the onset of failure should also be introduced.
4. Glossary of Terms

4.1 Useful Acronyms

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<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AEO</td>
<td>All Engines Operative</td>
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<tr>
<td>ALARP</td>
<td>As Low As Reasonably Possible</td>
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<tr>
<td>DEFSTAN</td>
<td>DEFence STANdard</td>
</tr>
<tr>
<td>DNAE</td>
<td>Day, Night, All Environment</td>
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<tr>
<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>ELT</td>
<td>Emergency Location Transmitter</td>
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<tr>
<td>HIGE</td>
<td>Hover In Ground Effect</td>
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<tr>
<td>HOGE</td>
<td>Hover Out of Ground Effect</td>
</tr>
<tr>
<td>ICAO</td>
<td>International Civil Aviation Organisation</td>
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<tr>
<td>ILS</td>
<td>Instrument Landing System</td>
</tr>
<tr>
<td>ISA</td>
<td>International Standard Atmosphere</td>
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<tr>
<td>JAR</td>
<td>Joint Airworthiness Requirements</td>
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<tr>
<td>KTAS</td>
<td>Knots – True AirSpeed</td>
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<tr>
<td>LEq</td>
<td>Equivalent Continuous Noise Level</td>
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<tr>
<td>MAUM</td>
<td>Maximum All Up Mass</td>
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<tr>
<td>MLS</td>
<td>Microwave Landing System</td>
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<tr>
<td>MOB</td>
<td>Main Operating Base</td>
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<tr>
<td>MVL</td>
<td>Medium Versatile Lift</td>
</tr>
<tr>
<td>OAT</td>
<td>Outside Air Temperature</td>
</tr>
<tr>
<td>OEI</td>
<td>One Engine Inoperative</td>
</tr>
<tr>
<td>TBO</td>
<td>Time Between Overhaul</td>
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