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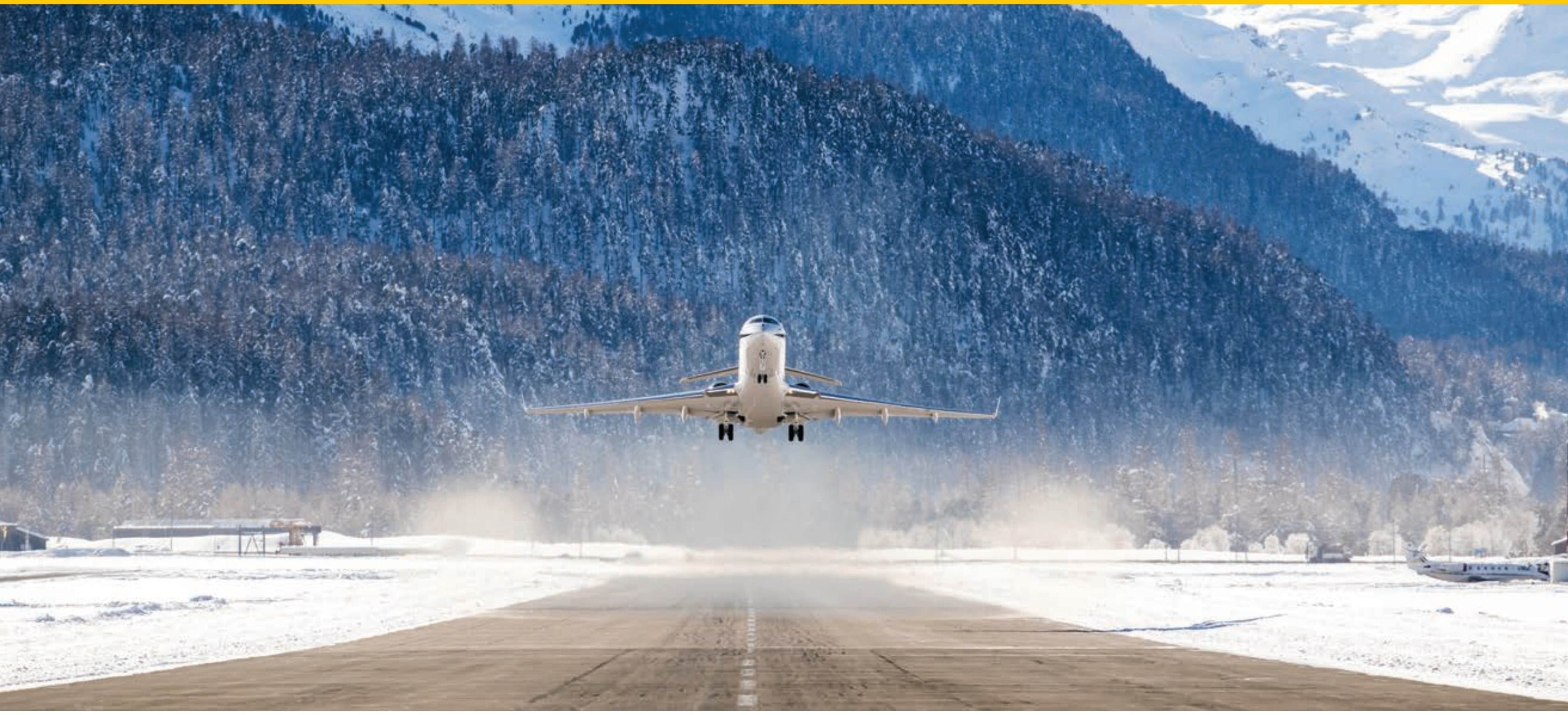
Manual on High Elevation Aerodrome Operations

First Edition, 2022



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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA			
No.	Date	Language	Entered by

FOREWORD

At the 39th Session of the Assembly (27 September to 6 October 2016), the Technical Commission deliberated A39-WP/336 Revision No. 1, presented by China on the *Operations at Plateau Airports*. This paper introduced the difficulties faced by aeroplane operations into or out of high elevation aerodromes (usually in mountainous areas) and recommended that appropriate considerations be given to the challenges presented by the operating environments of these aerodromes. The Technical Commission submitted the proposal included in the working paper to the Council for further deliberation in A39--WP/476, *Draft text for the Report on Agenda Item 35*. At the 40th Session of the Assembly (24 September to 4 October 2019), China presented A40-WP/304, *Updates on the Operation at High Elevation Aerodromes* to the Technical Commission, calling for support for ICAO in working with States, industry and other stakeholders for the standardization of optimum practices in high elevation aerodrome (HEA) operations and the development of globally harmonized Standards and Recommended Practices (SARPs).

The Flight Operations Panel discussed generic difficulties faced by the State of the Operator in regulating HEA operations and the challenges posed to the State of the Operator in HEA operational oversight, and potential safety risks to operators in HEA operations due to the lack of harmonized standards and guidelines worldwide. The panel agreed on the necessity for the State of the Operator to accept or authorize HEA operations, as applicable, due to their special nature.

This manual is intended to provide guidance to commercial operations in accordance with Annex 6 — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes* and is therefore focused on the operation of aeroplanes to high elevation aerodromes, by operators who are assumed to have a Safety Management System as required by Annex 19 — *Safety Management.*

Comments on this manual, particularly with respect to its application and usefulness, are appreciated. These comments will be taken into consideration in the preparation of subsequent editions. Comments concerning this manual should be addressed to:

The Secretary General
International Civil Aviation Organization
999 Robert-Bourassa Boulevard
Montréal, Quebec, Canada H3C 5H7

CONTENTS

GLOSSARY

When the following terms are used in this manual, they have the following meanings:

Extremely high elevation aerodrome (EHEA). An aerodrome at or above an elevation of 3 650 m (12 000 ft).

Hazard. A condition or an object with the potential to cause or contribute to an aircraft incident or accident.

High elevation aerodrome (HEA). An aerodrome at or above an elevation of 2 450 m (8 000 ft).

High elevation aerodrome (HEA) operation. An operation departing from and/or arriving at an HEA.

Risk mitigation. The process of incorporating defences, preventive controls or recovery measures to lower the severity and/or likelihood of a hazard's projected consequence.

Safety management system. A systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures.

Safety risk. The predicted probability and severity of the consequences or outcomes of a hazard.

Significant system for high elevation aerodrome (HEA) operations. An aeroplane system whose failure or degradation could adversely affect safety, particularly during an HEA operation, or whose continuous functioning is specifically important for the flight safety and landing of an aeroplane during a diversion of an HEA operation.

State of the Operator. The State in which the operator's principal place of business is located or, if there is no such place of business, the operator's permanent residence.

Ultra high elevation aerodrome (UHEA). An aerodrome at or above an elevation of 3 050 m (10 000 ft) but below 3 650 m (12 000 ft).

Very high elevation aerodrome (VHEA). An aerodrome at or above an elevation of 2 450 m (8 000 ft) but below 3 050 m (10 000 ft).

ACRONYMS AND ABBREVIATIONS

APU	Auxiliary power unit
CFIT	Controlled flight into terrain
EGT	Exhaust gas temperature
EHEA	Extremely high elevation aerodrome
HEA	High elevation aerodrome
hPa	Hectopascal
IFSD	In-flight shutdown
MEA	Minimum en-route altitude
MEL	Minimum equipment list
PIC	Pilot-in-command
SMS	Safety management system
UHEA	Ultra high elevation aerodrome
VHEA	Very high elevation aerodrome

Chapter 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 There were 64 civil aerodromes at or above an elevation of 2 450 m (8 000 ft) throughout the world as of 2019, distributed in 10 nations and mainly concentrated in the Himalayan Range in Asia and the Andes Range in South America. In these high elevation regions, climate is highly complicated; aeroplane performance is severely affected due to thinner air and operational personnel are vulnerable to slow cerebration, lapse error, slip error and mistakes because of the hypoxic environment. When these high elevation aerodromes (HEAs) are surrounded by complex terrain, significant challenges are often experienced in the development of flight procedures and the conduct of flight operations. A combination of these factors makes it highly challenging to fly into or out of these aerodromes.

1.1.2 The increased HEA operations bring forth greater challenges to the State of the Operator in the management of operational authorization, airworthiness maintenance, flight operations, operational personnel training and qualifications, and operations monitoring.

1.2 PURPOSE

1.2.1 This manual presents guidance in support of the management of safety risks associated with HEA operations, including details of the relevant operational experience, standards, and best practices, and provides the relevant policies, procedures and guidelines for the State of the Operator and operators worldwide.

1.2.2 This manual is intended to provide:

a) the State of the Operator with guidance for the development of national HEA operational policies and in the oversight of the HEA operations by its operators; and

b) the operators with guidance on the conduct of HEA operations.

1.3 APPLICABILITY

This manual applies to the use of aeroplanes by commercial air transport operators in passenger operations to or from an HEA. General aviation (aeroplane) operators may also refer to the guidance contained herein.

1.4 CHARACTERISTICS OF HEA OPERATIONS

HEA operations are usually accompanied by a complex operational environment and in general have the following characteristics compared with the operations at non-HEA airports:

1.4.1 Challenging environment

1.4.1.1 Major environmental concerns for HEA operations include, among other things, high altitude, complex terrain and frequently changing weather patterns.

1.4.1.2 HEAs are characterized by thinner air, lower air density, decreased atmospheric pressure and greater deviation from international standard atmosphere. Most HEAs are built in high mountain regions and surrounded by complex terrain, posing significant difficulties to the development of flight procedures and the installation of navigation infrastructure.

1.4.1.3 Most HEAs feature local weather conditions as a result of the combined effects of surface heat radiation, high-level jet streams and mountain waves. With huge temperature swings both between day and night and between the seasons, these aerodromes often experience rapidly changing weather along with strong winds, turbulence and wind shear, especially in the afternoon. Thunderstorms occur most often in the later afternoon and evening during the rainy season.

1.4.2 Degraded aeroplane performance

1.4.2.1 Due to decreased air density at HEAs, engine thrust is considerably reduced, aeroplane performance is affected and true airspeed, turning radius and ground speed are markedly increased. Consequently, the aeroplane's acceleration/deceleration response becomes slower, the required take-off and landing distances are increased considerably and engine failures will be compounded by the decreased climb performance and obstacle clearance capabilities.

1.4.2.2 In addition, compressor and turbine efficiency may be affected due to lowered auxiliary power unit (APU) or ground cart air pressure. During start-up, the engine accelerates more slowly than at non-HEAs and may be prone to exhaust gas temperature (EGT) limit exceedance and hung starts.

1.4.3 Significant physiological effects

1.4.3.1 According to Graham's Law, a gas will diffuse from an area of high concentration to an area of low concentration and diffusion velocity is inversely proportional to the square root of gas density.

1.4.3.2 Moreover, Dalton's Law states that the total pressure of a mixture of gas is equal to the sum of the partial pressure of each gas in the mixture.

1.4.3.3 At high altitude, both the atmospheric pressure and oxygen pressure in the atmosphere decrease and an individual's ability to obtain and utilize oxygen is dramatically affected. Because of poor gas exchange within the lungs, the body or a region of the body is deprived of adequate oxygen supply at the tissue level, which is referred to as "hypoxia".

1.4.3.4 The effects of hypoxia at different altitudes are as follows (adapted from the *Manual of Civil Aviation Medicine* (Doc 8984), Table II-1-2):

> *After a period of resting at 3 050 m (10 000 ft), an individual's more complex cerebral functions such as making mathematical computations begin to suffer.*
>
> *At the altitude of 3 650 m (12 000 ft), in addition to some arithmetical computation difficulties, short-term memory begins to be impaired and errors of omission increase with extended exposure.*
>
> *At the altitude of 4 250 m (14 000 ft), all persons are impaired to a greater or lesser extent with respect to mental function including intellectual and emotional changes.*

1.4.3.5 All cells in the human body require oxygen to function. The central nervous system (made up of the brain and spinal cord) demands a great deal of oxygen (approximately 20 per cent of all oxygen that a person inhales feeds the brain). If the oxygen supply to the body is reduced, the brain will be one of the first organs to be affected, with the higher reasoning portions of the brain showing degraded function first. This means that judgment and cognitive skills diminish from the very start. A pilot experiencing hypoxia has a limited amount of time to recognize the early signs and symptoms. Because advanced symptoms of hypoxia impair functions critical to safe flight, hypoxia poses the greatest potential physiological hazard to a flight crew member while flying in the high-altitude environment.

Table 1-1. Signs and symptoms of hypoxia

Subjective symptoms			*Objective signs*
Breathlessness; dyspnoea			Hyperpnoea or hyperventilation
Headache			Yawning
Dizziness (giddiness)	I	H	Tremor
Nausea	N	Y	Sweating
Feeling of warmth about face	C	P	Pallor
Dimness of vision	R	O	Cyanosis
Blurring of vision	E	X	Drawn, anxious facies
Double vision (diplopia)	A	I	Tachycardia
Confusion; exhilaration	S	A	Bradycardia (dangerous)
Sleepiness	I		Poor judgement
Faintness	N		Slurred speech
Weakness	G		Incoordination
Stupor	↓		Unconsciousness; convulsions

From Doc 8984 — Manual of Civil Aviation Medicine, Table II-1-3.

1.5 HEA CLASSIFICATION

Based on the analysis of an aeroplane performance degradation curve, the need for a supplemental oxygen supply and the design logic of cabin pressurization, this manual introduces a concept of HEA classification in policy development for operational personnel training, flight operations, airworthiness maintenance and an authorization process.

Very high elevation aerodromes: for flights departing from or arriving at these aerodromes, the operator should consider the obvious degradation in aeroplane performance.

Ultra high elevation aerodromes: for flights departing from or arriving at these aerodromes, the operator should consider the need for a continuous oxygen supply for operational personnel, modified and new equipment and supplementary operating procedures.

Extremely high elevation aerodromes: for flights departing from or arriving at these aerodromes, the operator should address the significant degradation in aeroplane performance, set stricter requirements for operational personnel skills and experience, and set additional specific requirements for flight crew training and qualifications, aeroplane systems and equipment, and special operating procedures.

Chapter 2

SAFETY RISK ASSESSMENT

2.1 The operator should manage the safety risks related to HEA operations under its safety management system (SMS), and conduct a proper safety risk assessment following the relevant policies established by the State of the Operator and the aeroplane manufacturer, in order to identify potential hazards and their associated consequences, conduct safety risk assessments, identify potential unintended consequences, and develop effective safety risk mitigation strategies.

2.2 Based on the identification of hazards related to HEA operations, safety risks associated with the potential consequences of those hazards should be assessed in line with the *Safety Management Manual* (Doc 9859). Table 2-1 presents an example of a safety risk matrix used to identify the level of safety risk tolerability as outlined in Table 2-2. Table 2-3 presents how the initial safety risk index could be reduced to an acceptable level through the application of appropriate mitigation measures described in relevant chapters of this manual.

Table 2-1. Example safety risk matrix

Safety Risk		*Severity*				
Probability		*Catastrophic* *A*	*Hazardous* *B*	*Major* *C*	*Minor* *D*	*Negligible* *E*
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Note.— In determining the safety risk tolerability, the quality and reliability of the data used for the hazard identification and safety risk probability should be taken into consideration.

Table 2-2. Example of safety risk tolerability index

Safety Risk Index Range	*Safety Risk Description*	*Recommended Action*
5A, 5B, 5C, 4A, 4B, 3A	INTOLERABLE	Take immediate action to mitigate the risk or stop the activity. Perform priority safety risk mitigation to ensure additional or enhanced preventative controls are in place to bring down the safety risk index to tolerable.
5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	TOLERABLE	Can be tolerated based on the safety risk mitigation. It may require management decision to accept the risk.
3E, 2D, 2E, 1B, 1C, 1D, 1E	ACCEPTABLE	Acceptable as is. No further safety risk mitigation required.

Table 2-3. Example mitigation and residual risk

Item	*Safety consequence*	*Safety risk index*	*Reference to mitigation measures outlined in this manual*	*Residual safety risk index*
1	Incapacitation due to hypoxia	5C	3.1 4.2 a) 5.1 6.3.1	**1C**
2	Human error due to increased possibility of fatigue	5D	3.2 3.3 4.5 5.1	**3D**
3	Runway excursion	3B	3.3.1 4.4 5.2 6.3.1	**2B**
4	Tail strike	3C	3.3.1 4.4 5.2	**2C**
5	Tire speed limit exceedance	4C	3.3.1 4.4 5.2 6.3.1	**2C**
6	Brake energy exceedance	4D	3.3.1 4.4 6.3.1	**2D**

Item	*Safety consequence*	*Safety risk index*	*Reference to mitigation measures outlined in this manual*	*Residual safety risk index*
7	Insufficient climb gradient in engine-out take-off/missed approach	2B	4.4 4.5.2 5.2 6.3.1 6.5 6.6	**1B**
8	Engine-out ceiling lower than minimum en-route altitude (MEA)	2B	4.4 4.5.2 5.2 6.3.1 6.5 6.6	**1B**
9	Limitations exceedance due to jammed slat/flap (en route and landing)	3B	3.3.1 6.3.1 6.4 6.7	**2B**
10	Unable to descend to 10 000 ft due to high MEA in the event of depressurization	3B	3.3.1 3.3.2 4.2 a) 4.2 b) 5.3	**2C**
11	Insufficient passenger oxygen	5C	4.2 a) 6.3.1	**1C**
12	Unintended in-flight situation due to unexpected adverse weather	5D	3.3.1 4.5 5.3	**4E**
13	Degraded radio navigation and communication	5D	3.3.1 6.4 6.7	**3E**

2.3 It should be noted that the residual index values quoted in Table 2-3 are provided as an example of the result of the safety risk assessment after the application of mitigation measures, and that the operator should perform specific analysis and assessment for each HEA operation to identify the safety hazards and potential safety consequences, and then assess the safety risks and the residual safety risks after applying the mitigation measures in accordance with its operational characteristics. In addition to Table 2-3, the operator may take into account potential safety consequences from other hazards related to pilot flying skills and mental stress, controlled flight into terrain (CFIT), aircraft upset, ground services (that is, anti/de-ice, oxygen refilling, refueling and search and rescue), APU bleed performance, engine start, low temperature correction, minimum safe altitude, etc., and mitigate the safety risks to an acceptable level through appropriate mitigation measures.

2.4 Furthermore, the effectiveness of the safety risk mitigation measures and/or strategies will need to be verified once they are put in place, to determine if any further action is required to ensure the safety risk management is effective. The effectiveness of safety risk mitigation measures could be verified through audits, and also monitored through the use of appropriate safety performance indicators (SPIs).

Chapter 3

OPERATIONAL PERSONNEL REQUIREMENTS

3.1 AVIATION MEDICINE

3.1.1 The operator should develop health management procedures for operational personnel engaged in HEA operations.

3.1.2 No operational personnel (flight crew member, cabin crew member, flight engineer, etc.) may be assigned to UHEA or EHEA operations when diagnosed with an acute upper respiratory infection (such as a cold), chronic bronchitis, emphysema, hypertension (high blood pressure), sleep disorder or other illness which may affect physiological tolerance to hypoxia.

3.2 FATIGUE MANAGEMENT

Operational personnel are more subject to fatigue due to a lower percentage of oxygen in the air and complex operational environment in high elevation areas. The operator should implement mitigation measures based on the fatigue risk analysis and develop specific limitations for operational personnel that differ from non-HEA operations, including limitations on the number of HEA take-offs and landings and HEA duty time, etc.

Note.— For more information on fatigue management, see the Manual for the Oversight of Fatigue Management Approaches *(Doc 9966).*

3.3 TRAINING AND QUALIFICATION

The operator should develop a specific training programme for HEA operations and specify the training curriculum, training methods and duration of training as applicable for each classification of HEA. The operator should ensure that all operational personnel involved in HEA operations have satisfactorily accomplished the necessary training and maintain relevant knowledge in a timely manner.

3.3.1 Flight crew

3.3.1.1 Considering the specific HEA classification and the specialties and challenges of the specific HEA operation, the operator should select flight crew members based on a comprehensive assessment of total flight time, experience in the aeroplane type and individual safety record, and ensure they are qualified for HEA operations upon completion of training.

3.3.1.2 The operator should tailor the training programme and methods to the specific HEA classification and the aeroplane type. For training methods, the operator may refer to Table 3-1 as follows:

Table 3-1. Typical training methods

HEA classification	*Ground course*	*Simulator training*	*HEA operating experience*
VHEA	√	–	–
UHEA	√	√*	–
EHEA	√	√	√

*Note.— The * indicates the operator may substitute simulator training with operating experience.*

3.3.1.3 Flight crew training curriculum for HEA operations should include but not be limited to:

a) HEA operational policies and requirements;

b) HEA environment characteristics;

c) high elevation physiology;

d) knowledge of survival and rescue in high elevation areas;

e) supplementary aeroplane operating procedures, if any;

f) crew/passenger oxygen system limitations and oxygen supply requirements;

g) special operating procedures in case of performance degradation;

h) HEA characteristics-oriented aeroplane control (take-off, landing and missed approach);

i) instrument/visual procedures (arrival/departure) as applicable for a specific HEA;

j) engine-out emergency procedures (take-off, en route, approach and missed approach);

k) cabin depressurization procedure; and

l) drills for failures of significant systems for HEA operations.

3.3.2 Cabin crew

Cabin crew training curriculum for HEA operations should include but not be limited to:

a) HEA operational policies and requirements;

b) knowledge of survival and rescue in high elevation areas;

c) characteristics and general treatment of altitude sicknesses;

d) high elevation physiology; and

e) cabin depressurization procedure.

3.3.3 Maintenance personnel

Maintenance personnel engaged in aeroplane maintenance and release should receive relevant training. The training curriculum should include but not be limited to:

a) maintenance management requirements for HEA operations;

b) significant systems for HEA operations;

c) aeroplane maintenance programme for HEA operations;

d) minimum equipment list (MEL) items for HEA operations, if any;

e) service check policy for HEA operations;

f) dual maintenance limitations for HEA operations; and

g) complex maintenance tasks for HEA operations.

3.3.4 Flight dispatchers/flight operations officers

Flight dispatchers/flight operations officers involved in flight dispatch and monitoring of HEA operations should complete the relevant training. The training curriculum should include but not be limited to:

a) HEA operational policies and requirements;

b) HEA terrain and climate characteristics;

c) HEA environmental impact upon aeroplane performance; and

d) emergency procedures of the specific HEA.

3.4 PILOT-IN-COMMAND (PIC) RECENT EXPERIENCE

3.4.1 Given the challenges brought forth by HEA operations to the flight crew, the fact that one is familiar with the specific environmental characteristics and flight procedures is of great importance to the safety of HEA operations. The operator should consider developing PIC recent experience requirements for HEA operations in line with Annex 6 — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes*, Chapter 9, 9.4.3.5.

3.4.2 For instance, the PIC scheduled for EHEA operations may have had to perform at least one take-off and landing at an EHEA as a required crew member within twelve calendar months preceding the month of the flight. This requirement may also be met in a flight simulator approved for this purpose.

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Chapter 4

OPERATOR REQUIREMENTS

4.1 SAFETY MANAGEMENT

The operator should ensure that qualified personnel, equipment, facilities and documents necessary for the safety of HEA operations, are available. The operator should also manage HEA operations-related safety risks following the relevant policies and requirements established by the State of the Operator.

At the State level, special requirements should be established to manage the safety of HEA operations. Since HEA operations are subject to specific safety risks that may not be acceptable without the application of effective mitigation measures (see the example provided in Table 2-3), the State of the Operator should assess the need to require the operator to manage HEA operations under its SMS.

4.2 AEROPLANE CONFIGURATION

Specific configuration packages for HEA operations provided by the aeroplane manufacturer (Airbus HAO kit or Boeing High Hot package, etc.) are recommended, if any should be considered. In particular, the following should be addressed:

a) A sufficient quantity of oxygen should be carried for HEA operations. For UHEA and EHEA operations, the need for supplemental oxygen supply for crew members and passengers suffering from hypoxia should also be considered. Oxygen quantity should conform to the requirements of Annex 6, Part I, Chapter 4, 4.3.9 as follows:

   "4.3.9.1 A flight to be operated at flight altitudes at which the atmospheric pressure in personnel compartments will be less than 700 hPa shall not be commenced unless sufficient stored breathing oxygen is carried to supply:

   "a) all crew members and 10 per cent of the passengers for any period in excess of 30 minutes that the pressure in compartments occupied by them will be between 700 hPa and 620 hPa; and

   "b) the crew and passengers for any period that the atmospheric pressure in compartments occupied by them will be less than 620 hPa.

   "4.3.9.2 A flight to be operated with a pressurized aeroplane shall not be commenced unless a sufficient quantity of stored breathing oxygen is carried to supply all the crew members and passengers, as is appropriate to the circumstances of the flight being undertaken, in the event of loss of pressurization, for any period that the atmospheric pressure in any compartment occupied by them would be less than 700 hPa. In addition, when an aeroplane is operated at flight altitudes at which the atmospheric pressure is less than 376 hPa, or which, if operated at flight altitudes at which the atmospheric pressure is more than 376 hPa and cannot descend safely within four minutes to a flight altitude at which the atmospheric pressure is equal to 620 hPa, there shall be no less than a 10-minute supply for the occupants of the passenger compartment."

b) The cabin pressurization systems installed should be type certificated or approved through other means to ensure they meet the requirements of take-offs and landings at different classifications of HEAs; and

c) Other items such as required navigation performance authorization required capability, high-speed tire, winglet and deceleration devices that could benefit HEA operations, should also be considered.

4.3 HEA OPERATIONS MANUAL

The HEA operations manual may be developed either in the form of a separate manual or by incorporating relevant requirements for HEA operations into the operator's operations manual.

4.4 AEROPLANE PERFORMANCE

4.4.1 Due to the surrounding complex terrain at most HEAs, the operator should evaluate the aeroplane take-off, landing and missed approach performance, and perform analyses of en route drift-down and oxygen supply duration. The operator should develop engine-out procedures, cabin depressurization procedures and other emergency procedures for each specific HEA to be used.

4.4.2 For operations at aerodromes elevated between 1 500 m (5 000 ft) and 2 450 m (8 000 ft), since there will be a slight decrease in aeroplane performance and no obvious high-altitude related operational safety risks are observed, extra consideration may not be needed.

4.5 SUPPLEMENTARY AEROPLANE OPERATING PROCEDURES

Based on the aeroplane configuration, performance and operating limitations, and taking into account the HEA terrain and weather conditions, the operator should develop supplementary operating procedures as needed for each aeroplane type.

4.5.1 Engine start

To minimize the possibility of start failure (hung start, hot start, etc.), the operator should develop special start procedures and limitations to increase inlet air and reduce start load.

4.5.2 Engine/APU bleed

4.5.2.1 To address aeroplane performance limitations or terrain constraints, the operator should develop supplementary operating procedures for "air conditioning off" or "no engine bleed air" take-off, in order to meet the minimum climb gradient while optimizing the payload.

4.5.2.2 Unpressurized (all packs off or all bleeds off) take-off procedure is not recommended for HEA operations.

4.5.3 Pressurization system operation

4.5.3.1 The operator should evaluate the operation of the pressurization system for the aeroplane type to be used. If needed, supplementary procedures should be developed to prevent an unexpected pressurization profile or cabin altitude warning.

4.5.3.2 At EHEAs, it may be necessary to develop supplementary operating procedures to modify the procedures for pressurization (manual depressurizing procedures on ground, high altitude landing switch operating procedures, etc.), in order to adapt the aeroplane to the high elevation environment.

4.5.4 Flight crew supplemental oxygen

4.5.4.1 The most significant impact of HEA operations upon flight crew is high altitude hypoxia. From the perspective of civil aviation medicine, altitude and duration of exposure are two of the most influential factors of hypoxia.

4.5.4.2 Based on hypoxia's effects upon intellectual function, physical performance and the time of useful consciousness, civil aviation medicine divides the atmosphere into the following four zones:

a) indifferent zone: between 0 and 3 050 m (10 000 ft). A resting individual can maintain sufficient compensatory capacity because of the low level of hypoxia. There are no obvious symptoms except for night vision, which starts to decrease from around 1 200 m (4 000 ft). However, from 1 500 m (5 000 ft) and above, the ability to complete complex mental tasks begins to be affected; after a several-hour stay or heavy physical labour at 3 050 m (10 000 ft), hypoxia symptoms may become obvious;

b) complete compensatory zone: between 3 050 m and 5 000 m (10 000 ft and 16 500 ft). The heart rate and pulmonary ventilation rate show an obvious increase. The body's compensatory reaction can still adapt to the environment and hypoxia symptoms are not severe for a resting individual after a short stay. However, a closer examination can find that the intellectual function to perform complex and precision work has been apparently diminished and the ability to perform heavy physical labour obviously reduced. When a long stay is combined with certain physical load or abnormal environmental factors (such as high temperature), symptoms will become more pronounced;

c) partial compensatory zone: between 5 000 m and 7 000 m (16 500 ft and 23 000 ft). Although the compensation reaction has fully taken effect, the effects of hypoxia cannot be compensated. Even a seated human may show obvious dysfunctions and mental and physical abilities are severely affected. Except for such symptoms as headaches, dizziness, blurred vision, emotional distress and muscular incoordination, intellectual functions are particularly impaired, causing slow thinking and impaired (or even loss of) judgment, comprehension and memory. Extended exposure normally does not cause loss of consciousness, except when physical labour is involved at 5 500 m (18 000 ft) or above; and

d) critical zone: above 7 000 m (23 000 ft). The compensatory capacity cannot ensure the minimum oxygen demand of the brain and other important organs. Exposure can rapidly lead to severe mental disorder and muscular incoordination. Loss of consciousness can be caused with extended exposure. Without immediate oxygen therapy, respiratory and circulatory paralysis can occur.

4.5.4.3 In addition, according to the simulated HEA operations in a hypobaric chamber, exposure time could adversely affect a flight crew member's blood oxygen saturation (SaO2). Table 4-1 shows how exposure time affects the SaO2 saturation.

Table 4-1. SaO2 saturation in simulated HEA operations

Aerodrome elevation	*SaO2 (Initial exposure)*	*SaO2 (One-hour continuous exposure)*
approx. 3 650 m (12 000 ft)	90%	85%
approx. 4 000 m (13 000 ft)	85%	80%
approx. 4 400 m (14 500 ft)	80%	75%

4.5.4.4 According to the research on simulated HEA operations in a hypobaric chamber and actual HEA operations, the decrease of blood oxygen saturation could lead to cognitive decline, resulting in the flight crew's underestimation of the riskiness of hypoxia or even being unaware of the onset of hypoxia.

4.5.4.5 Supplemental oxygen should be supplied to the flight crew when cabin altitude exceeds 3 050 m (10 000 ft) mean sea level (refer to Annex 6, Part I, Chapter 4, 4.4.5). The operator should specify oxygen use requirements for HEA operations to manage the relevant safety risks.

4.5.4.6 Among the multiple occurrences classified as incidents or serious incidents involved in HEA operations, the operators were found to have been using the emergency oxygen system as a source of supplemental oxygen for the flight crew. The cockpit emergency oxygen system is mainly used for sustenance in case of emergencies (for example, fire, smoke or loss of cabin pressure) and the oxygen masks also help the flight crew survive the smoke and toxic gases. The use of oxygen masks requires the users being seated and a good seal between the mask and the face. However, prolonged use of the mask may cause discomfort to the flight crew or even interfere with the manoeuvring of the aeroplane. In addition, the emergency oxygen system is not suitable for other occasions such as walkaround checks. For aerodromes where oxygen refilling service is not available, use of the installed oxygen system may affect the dispatch release of the flight.

4.5.4.7 The operator should assess the potential consequences of an aeroplane emergency oxygen system being used as a source of supplemental oxygen in HEA operations. To meet the need of supplemental oxygen, the operator should consider providing additional equipment, allowing for the safe and convenient use of supplemental oxygen for any pilot seated at the controls.

Note.— Typical solution of supplemental oxygen for a flight crew is a combination of a portable oxygen cylinder or a portable oxygen concentrator and individual oxygen equipment (e.g. mask or pipe).

Chapter 5

FLIGHT OPERATIONS REQUIREMENTS

5.1 OPERATIONAL PERSONNEL

Operational personnel to be assigned for HEA operations should meet the relevant requirements in Chapter 3 of this manual.

5.1.1 Flight crew pairing

When the operator schedules flight crew members for HEA operations, the factors that need to be considered include, but are not limited to, the following:

a) HEA operations qualifications;

b) HEA operations experience;

c) age;

d) health condition;

e) cockpit authority gradient; and

f) fatigue management.

5.2 SUPPLEMENTARY BRIEFING CARDS AND CHECKLISTS

Considering the specific HEA classification and the aeroplane type to be used, the operator should develop the appropriate supplementary briefing cards and checklists in order to reduce human errors and improve human performance in HEA operations.

5.3 OPERATIONAL CONTROL

5.3.1 Dispatch release

The operator should perform oxygen duration analysis for the intended route in the event of depressurization. If needed, a contingency plan should be developed.

Chapter 6

MAINTENANCE AND RELIABILITY REQUIREMENTS

The operator should determine how to adapt its existing maintenance programme based on an assessment of the risks and characteristics of its specific HEA operations, in order to ensure it has an effective HEA maintenance system and qualified maintenance personnel and the aeroplane is properly maintained for HEA operations. Maintenance and reliability requirements for aeroplanes used for HEA operations could be developed with reference to relevant elements in Doc 10085, *Extended Diversion Time Operations (EDTO) Manual*, as it provides a basis for enhanced reliability standards.

6.1 MAINTENANCE PROGRAMME FOR HEA OPERATIONS

6.1.1 In the context of this manual, the term "maintenance programme for HEA operations" refers to the maintenance related elements that must be implemented by the operator to support its HEA operations.

6.1.2 Maintenance programme for HEA operations may be developed either in the form of a separate manual or by incorporating relevant requirements for HEA operations into the operator's maintenance programme.

6.1.3 The typical elements of a maintenance programme for HEA operations are identified as follows:

a) maintenance management procedures;

b) significant systems for HEA operations;

c) aeroplane maintenance programme for HEA operations;

d) service check policy for HEA operations;

e) dual maintenance limitations;

f) complex maintenance tasks control;

g) HEA operations reliability programme;

h) engine condition monitoring programme; and

i) minimum equipment list (MEL) for HEA operations.

6.1.4 The required elements of the maintenance programme for HEA operations should be authorized by the State of the Registry in conjunction with the applicable aeroplane maintenance programme, MEL, reliability programme and training programme, to ensure that they meet the specific maintenance requirements.

6.2 MAINTENANCE MANAGEMENT PROCEDURES

The purpose of maintenance management procedures is to provide involved personnel with a descriptive means aimed at ensuring safe and efficient HEA operations, which should at least address the following elements:

a) general information on applicable HEA operations rules and the operator's HEA operations programme;

b) responsibilities (maintenance control centre, engineering, quality, training, production planning, etc.);

c) maintenance procedures for HEA operations (maintenance release, HEA operations service check, complex maintenance tasks, engine condition monitoring, etc.); and

d) processes (daily review, reporting, dual maintenance limitations, etc.).

6.3 CONTROL OF THE SIGNIFICANT SYSTEMS FOR HEA OPERATIONS

6.3.1 Significant systems for HEA operations

Following this section's guidance and the aeroplane manufacturer's recommendations (if any), the operator should develop a list of systems for HEA operations for each aeroplane type in accordance with the specific HEA classification, operating environment (including weather, terrain, obstacles) and the concerned fleet of aeroplanes. The following table presents an example of typical significant systems for HEA operations and considerations when performing a safety risk assessment for HEA operations.

Table 6-1. Typical significant systems for HEA operations

Item	*System*	*Considerations*
1	Air conditioning and pressurization	a) Aeroplane oxygen endurance may be inadequate when the MEA restriction prevents the aeroplane from descending directly to a safer and lower altitude in the event of cabin depressurization. b) Air conditioning packs and avionics are more likely to overheat due to thinner ambient air. c) Oxygen masks are more likely to drop off automatically due to approach to the design ceiling of cabin pressurization especially when the aerodrome elevation is extremely high.
2	Auto pilot	Controlled flight into terrain (CFIT) likelihood is increased as a result of difficulties in maintaining flight track without an auto flight system when traversing complex terrain.
3	Flight controls	a) Manoeuvrability is decreased by degraded control. b) Obstacle clearance or landing performance may not be met when slats/flaps are jammed. c) Deceleration efficiency is reduced by spoiler failures.

Item	*System*	*Considerations*
4	Hydraulic	Landing gear operation, flight control, brakes, etc. may be impacted when hydraulic system fails.
5	Landing gear	a) Tire burst may occur due to high ground speed. b) Higher brake energy and overheating are caused by high ground speed.
6	Navigation	a) CFIT likelihood is increased by track deviations in the event of navigation system failure or degradation. b) Unexpected adverse weather conditions are frequent at HEAs. c) CFIT likelihood may increase in the event of ground proximity warning system malfunctions.
7	Oxygen	Supplemental oxygen supply is needed for HEA operations when the cabin altitude exceeds 3 050 m (10 000 ft).
8	Auxiliary power unit (APU)	Aeroplane performance or pressurization may be affected when APU fails.
9	Engines	a) More reliable engines with greater safety margins are needed for HEA operations. b) Thrust reversers can help decelerate the aeroplane and reduce workload on the brakes.

6.3.2 Management requirements

In order to mitigate the safety risks to an acceptable level, the operator should make appropriate revisions to airworthiness documents such as an aeroplane maintenance programme, reliability programme and MEL, considering its list of significant systems.

6.4 AEROPLANE MAINTENANCE PROGRAMME FOR HEA OPERATIONS

6.4.1 The operator should develop maintenance control processes for the following maintenance tasks performed on significant systems for HEA operations:

a) all scheduled tasks that affect significant systems for HEA operations, coming typically from the maintenance review board report, maintenance planning document or certification maintenance requirements documents; and

b) complex maintenance tasks affecting significant systems for HEA operations.

6.4.2 The aeroplane maintenance programme for HEA operations may be developed by incorporating relevant requirements for HEA operations into the current aeroplane maintenance programme.

6.4.3 The aeroplane maintenance programme for HEA operations should include:

a) service check items for HEA operations;

b) dual maintenance limitations; and

c) complex maintenance tasks control.

6.4.4 Service check policy for HEA operations

6.4.4.1 The operator should implement a service check policy for HEA operations before starting HEA operations in order to assess the operation of HEA significant systems and confirm whether the aeroplane technical status is acceptable for HEA operations.

6.4.4.2 Based on the list of significant systems for HEA operations, the operator should incorporate HEA operations required items into the relevant service checks (for example, pre-flight, daily, weekly), taking into account the specific HEA classification and operating environment (including weather and terrain).

6.4.4.3 The check should be performed by maintenance personnel who have accomplished relevant maintenance training for HEA operations.

6.4.5 Dual maintenance limitations

6.4.5.1 Dual maintenance is commonly defined as any maintenance performed on the same element of identical but separate systems. Dual maintenance performed on HEA significant systems during the same routine or non-routine maintenance visit could cause duplication of a same human error into redundant components of the same system or function, which could cause dual system failure, leading to degraded configurations that may adversely impact HEA operations.

6.4.5.2 The operator should not perform scheduled or unscheduled dual maintenance during the same maintenance visit on significant systems for HEA operations.

6.4.5.3 In the event that dual maintenance cannot be avoided, the operator may perform maintenance provided that:

a) the tasks on each affected significant system for HEA operations are performed by different maintenance technicians; or

b) the tasks on each affected significant system for HEA operations are performed by the same maintenance technician under the direct supervision of another technician.

6.4.6 Complex maintenance tasks

6.4.6.1 The operator should identify complex maintenance tasks for HEA operations based on the results of a safety risk assessment.

6.4.6.2 It is suggested that the operator should take necessary additional verification measures (including run-up, test flight or non-HEA operations) after accomplishing complex maintenance tasks to ensure that all significant systems meet relevant requirements for HEA operations.

6.4.6.3 The complex maintenance tasks include, but are not limited to:

a) scheduled heavy maintenance;

b) major repair;

c) major modification;

d) engine replacement; and

e) troubleshooting for intermittent failures and repetitive failures related to the significant systems for HEA operations.

6.5 RELIABILITY PROGRAMME FOR HEA OPERATIONS

6.5.1 The operator should create a reliability programme for HEA operations based on its list of the significant systems. The programme should be designed to monitor items, at least covering the significant systems for HEA operations, with the objective of allowing early identification and prevention of HEA operations-related major incidents and ensure that HEA operations reliability is maintained.

6.5.2 The HEA operations reliability programme may be developed by incorporating additional requirements for HEA operations into a current reliability programme.

6.5.3 The programme should be event-oriented and incorporate reporting procedures for the following events:

a) in-flight shutdowns (IFSDs), except for planned IFSDs performed for flight training;

b) diversions or turn-backs for failures, malfunctions, or defects associated with the significant systems for HEA operations;

c) uncommanded power changes or surges;

d) inability to control the engine or obtain desired power; and

e) any other event that affects the safety of HEA operations.

6.5.4 An event-orientated analysis of each in-service event should be performed. This analysis should identify the root causes of the event and define the related corrective actions.

Note.— For more information regarding the development of a maintenance and reliability programme, see the Airworthiness Manual *(Doc 9760)*.

6.6 ENGINE CONDITION MONITORING PROGRAMME

6.6.1 The operator should implement an engine condition monitoring programme to detect deterioration at an early stage to allow for corrective actions before safe operation is affected. Engine margins preserved through this programme should also take into account the effect of additional engine loading demand which may be required during the single-engine flight phase associated with the HEA operation.

6.6.2 The engine condition monitoring programme for HEA operations may be developed by incorporating additional requirements for HEA operations into the current engine condition monitoring programme.

6.6.3 This programme should describe the parameters to be monitored, methods of data collection, methods of data analysis and the corrective action process.

6.6.4 The programme should aim at providing sufficient safety margins for engines, focusing on such elements as EGT, vibration, oil consumption and borescope-detected defects.

6.6.5 After an engine replacement, the operator should ensure the requirements of this section be met through the evaluation of the engine's operating conditions prior to HEA operations.

6.7 MINIMUM EQUIPMENT LIST (MEL)

6.7.1 Based on the list of significant systems, the operator should develop a MEL for HEA operations in accordance with the HEA classification and operating environment (including weather, terrain) to ensure that HEA significant systems effectively support the relevant requirements on HEA operations.

6.7.2 The MEL for HEA operations may be developed by incorporating any relevant additional dispatch restrictions for HEA flights into the current MEL.

6.7.3 The release requirements can vary for different HEA classifications but should be identified clearly in the MEL for HEA operations.

6.7.4 Release requirements contained in the MEL should be strictly followed. The defect deferral should be performed as per the MEL by HEA operations authorized maintenance personnel.

6.7.5 The operator should conduct continuous monitoring on the implementation of the MEL and evaluate its suitability periodically.

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Chapter 7

AUTHORIZATION PROCESS

7.1 REQUIREMENTS FOR THE STATE OF THE OPERATOR

7.1.1 The State of the Operator is responsible for authorizing HEA operations in the area(s) of operation based on its review of the applicant's procedures, operating experience, mature safety risk management process and overall safety record.

7.1.2 For instance, the State of the Operator should make a technical safety evaluation of each operator who applies for EHEA operations before issuing the authorization.

7.1.3 In the case of a technical safety evaluation, the State of the Operator should develop specific evaluation standards and appropriate guidance materials. The State of the Operator should consider operator variations in developing national operational standards and technical specifications tailored for specific operating environments and conditions. The safety evaluation should be conducted in accordance with the requirements of sections 7.2 and 7.3 of this manual.

7.1.4 In the case of acceptance, the State of the Operator should require the applicant to submit a preparation report for the proposed HEA operations, which should include, but not be limited to:

a) hazard identification, safety risk assessment and mitigation measures to be applied to achieve an acceptable level of safety risk;

b) required aeroplane configuration for HEA;

c) supplementary operating procedures;

d) training programme for operational personnel;

e) performance analysis; and

f) specific flight procedures.

7.2 REQUIREMENTS FOR THE OPERATOR

7.2.1 The applicant should have been in safe operation (that is, no serious incidents/accidents and no major findings raised by the authority) for at least 12 consecutive months, or their management personnel (for example, director of operations or chief pilot, and director of maintenance or chief engineer) should have at least three years of accumulated experience of flight operations or maintenance management in HEA operations during the past 10 years. Regarding the categories of HEA, the following should be considered:

a) for the applications for VHEA and UHEA operations, the State of the Operator may alleviate, as applicable, the above requirements for the operator's management personnel; and

b) for the applications for EHEA operations, all the above requirements should be met.

7.2.2 The configuration of the aeroplane to be used in HEA operations should meet the requirements of section 4.2 of this manual.

7.3 APPLICATION DOCUMENTS

The applicant should submit an application for HEA operations authorization along with the required documents to the State of the Operator. These documents include, but are not limited to:

a) the schedule of HEA operations;

b) self-assessment report of the management of operational safety risks relevant to the proposed HEA which must include identified hazards, associated safety risks assessments, mitigation measures to be applied to achieve an acceptable level of safety risks and means to validate the effectiveness of the mitigation measures (see the example provided in Chapter 2);

c) HEA operations manual or HEA chapter of existing operations manual (including HEA operations policy, maintenance policy, training programme, safety risk assessment and management, etc.); and

d) performance analysis and specific flight procedures (such as obstacle clearance, tire speed, braking energy, oxygen duration, take-off and landing performance).

7.4 REQUIRED TECHNICAL SAFETY EVALUATIONS

The State of the Operator should review the application for its completeness and compliance with the requirements of the relevant rules and regulations.

7.4.1 Document review

The State of the Operator should review whether the manuals submitted by the applicant are in compliance with its national policies, whether the self-assessment report of operational safety includes the main safety risks associated with the proposed HEA operations, and whether safety risk mitigation measures are practical.

7.4.2 Demonstration and evaluation

The State of the Operator should evaluate the applicant's ability to conduct safe HEA operations in both normal and abnormal situations. As for initial application for HEA operations, the demonstration can be conducted in a simulator or on an aeroplane.

7.4.3 Authorization

If the demonstration and evaluation phase has been completed satisfactorily, in addition to authorizations for the manuals and programmes (if applicable), the State of the Operator should include the authorized HEA area into the "area(s) of operation" field of the applicant's operations specifications.

— END —

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