CERTIFICATION CONSIDERATIONS FOR MICRO-GRAVITY FLIGHTS WITHIN THE UK

C.A. Quinn – City University, London

Abstract

The emergence of the Commercial Spaceflight Industry has provided opportunities for companies in regards of design, manufacture, operations and training. Within the latter field, parabolic flights to facilitate 'micro-gravity' experiences are regarded as integral to a spaceflight Operator's passenger training programme. Currently, there are no UK CAA regulations covering this activity. To enable micro-gravity flights to commence within the UK for spaceflight training, recreational flights and scientific studies, regulations and guidance need to be produced in advance to permit the activity.

This paper examines differing approaches to micro-gravity flight certification and the necessary methodology to ensure the safe management of the activity. The paper also presents the view that micro-gravity flights should be granted permission to fly, qualifying under the CAA's Certificate of Airworthiness by demonstration of compliance within defined modification and verification standards.

Author

C A Quinn MSc AMRAeS IEng
Safety Consultant
QinetiQ

1. Introduction

It is widely recognised within the Commercial Spaceflight Industry that vast progress is being made towards the first multi-passenger sub-orbital flight. Test flights of sub-orbital spacecraft are due to start during 2008 [1], with fare-paying passenger flights commencing late 2009. Multi-passenger commercial orbital flight development programmes are also progressing.
Sub-orbital and orbital flight profiles will involve varying levels of gravitational forces being exerted and experienced on the flight crew and passengers. In preparation for these flights, much work is being carried out with regards to design and manufacture in order to mitigate some of the hazards associated with commercial spaceflight. Operating hazards will be mitigated within a safety management framework and training analysis and development will be required for both flight crew and passengers. Micro-gravity flights that facilitate 'micro-gravity' are being considered as an important mitigation strategy as part of the training programme for the potential space passengers.

Additionally, opportunities exist in a commercial context for general recreational activities and also from a micro-gravity scientific research perspective.

In anticipation of applications for micro-gravity flights within the UK airspace, this paper examines the requirements of an operator in terms of meeting safety management criteria and suggests measures the CAA may take in assuring airworthiness standards are met, from a National and EASA perspective.

2. What is a Micro-Gravity Flight?

An aircraft micro-gravity flight is a profile carried out by specially certified and modified aircraft [2] in which periods of reduced gravity or weightlessness can be achieved within the aircraft. To achieve this, the aircraft executes a series of manoeuvres (parabolas) by climbing the aircraft steeply up to approximately 45 degrees, followed by a 'push-over' to descend steeply (figure 1). During the pushover and descent, the aircraft is in a ballistic trajectory resulting in a period of approximately 20 seconds of weightlessness prior to aircraft recovery and starting the manoeuvre again. Nominally, 20-30 parabolas can be performed for each flight with 2 minute intervals to achieve the right experience.

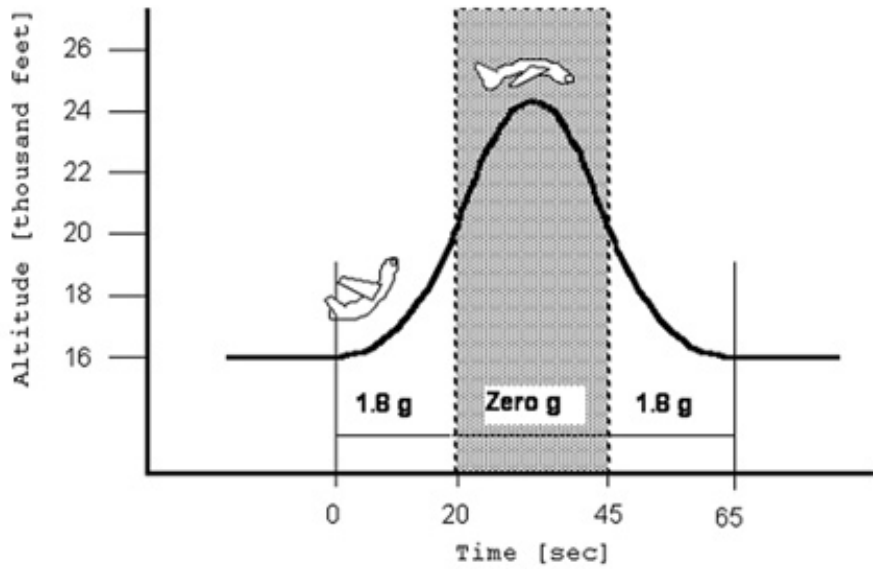

Figure 1 – A single parabola is depicted with the relevant gravitational forces experienced shown for each element of the manoeuvre. The shaded area is where 'weightlessness' occurs. The parabola is initiated from normal horizontal flight by pulling up through a 1.8g load factor, nosing up to approximately 45 degrees. At the pre-requisite altitude, the engine thrust is reduced and a rapid descent is initiated in a ballistic mode. This gives rise to the 'weightlessness' for approximately 20 seconds, after which a symmetrical pull-out through 1.8g is executed back to steady flight conditions. It can also be seen that the manoeuvre is conducted within a 10,000ft block of airspace and this can be carried out within a 10nm wide, 100nm long corridor.

3. Review of Current Requirements for Parabola Operators

There are 3 differing organisational approaches at present; Full Governmental programmes (NASA and the Russian Roscosmos Space Programme), Subsidiary-Governmental programmes (French Space Agency (CNES) - controlled NoveSpace) and a commercial venture (Zero-G Corp).

3.1 Governmental Programmes.
NASA and the Russian Roscosmos Space Programme have been operating parabola flights for over 45 years (more than 150,000 parabolas) without incident [3]. The purpose of these flights has been the conditioning and preparation of astronauts and cosmonauts for space missions. Micro-gravity training was also an essential part of the six civilian space tourist's programme, as they were considered to be an integral part of the crew.

3.1.1 Certification. The NASA KC-135 is not certified by the FAA. The Russian IL-76 is also not certified for public use.

3.1.2 Medical Requirements. Astronauts undergo a strict medical regime in order to cope with non-nominal excessive gravitational forces, decompression and weightlessness over a long period.

3.2 Subsidiaries-Governmental Programme.
ESA-CNES control NoveSpace [4] who operate the A300 Zero-G aircraft.

3.2.1 Certification. The aircraft is certified under a 'test flight' permit and as such, has stringent rules for the test campaigners.

3.2.2 Modifications. The A300 has been modified to meet EASA requirements.

3.2.3 Medical Requirements. An Aviation Authority Class III medical is required.

3.2.4 Experiment Requirements. Full test results and pre-flight safety visit to check equipment and documentation is required.

3.2.5 Insurance Requirements. Novespace have contracted in-flight individual insurance and civil liability insurance.

3.3 Commercial Venture.
Zero-G Corporation [5] is a privately held space entertainment and tourism company, based in Florida, USA.

3.3.1 Certification. The FAA has certified the Boeing 727-200 aircraft under a Supplementary Type Certificate (STC), operating under FAA Part 121 requirements.

3.3.2 Modifications. The major modification involved an upgraded hydraulic system to prevent cavitations during parabolas. Further to this, all systems were evaluated as to their integrity for parabolic flight. The aircraft is fitted

with accelerometers to assist in the parabola manouevres and during test flights, the aircraft was fitted with strain gauges for structural integrity checks.

3.3.3 Other Requirements. Unlike the requirements for governmental agencies, Zero-G only requires a medical questionnaire to be completed. A pre-flight safety briefing is given and passengers must also sign a waiver of liability. In essence, their philosophy is that if you can cope with a 'roller-coaster' ride, then you can cope with a parabola flight.

4. Review of UK CAA Regulatory Framework for Certification and Operation

The CAA is the UK's specialist independent aviation regulator. A review of the CAA procedures [6] indicates that micro-gravity flights can be integrated within the UK and EASA framework using current codes of practices, publications and guidelines. The following CAA activities were reviewed as to their relevance for micro-gravity flight certification:

4.1 Certification.
The Safety Regulation Group (SRG) [7] has full rulemaking and oversight to ensure safety and as such will be responsible for ensuring the micro-gravity Operator's certification process; additional compliance requirements due to necessary modifications and verifications will be required:

4.1.1 CAA CAP 747. Certification of Airworthiness in accordance with the ICAO Annex 8 is required on the standard aircraft.

4.1.2 CAA Supplementary Type Certification (STC). Following on from standard certification, an STC would be required to demonstrate that the aircraft has been modified under the approval of the CAA (EASA). Additionally, this may require an Airworthiness Approval Notice (AAN).

4.1.3 CAA/Operator Flight Testing. Flight Testing will be required as part of the certification process. As well as being carried out under the auspices of the CAA, the flights will also provide the flight crew with invaluable training experience. From this, the Operator will be able to establish Check Flight Schedules and Check Flight Handbooks in accordance with CAA requirements.

4.1.4 Continued Airworthiness. EASA Regulations require operators to ensure that their aircraft comply with applicable airworthiness requirements and remain airworthy – especially with modified systems, whereby additional maintenance procedures may be required.

4.2 Operations.

4.2.1 JAR-Ops. Operators will still be required to operate to JAR-Ops 1, subpart P for the standard operations and standard procedural elements of the flight.

4.2.2 ANO CAP 363. Operators will still be subject to the ANO and it is considered that because of the additional risks involved in the activity, micro-gravity flights would fall under ANO 157 3(a) as 'Public Transport'. However, an exception will have to be added to cover the specialist activity. The rationale being that the flight profile from start up to engine shutdown will be the same for normal Public Transport standards, except for the 'Recreational Aerial Activity' in the middle of the profile, which poses extra risk as mentioned in 4.2.5, below.

4.2.3 CAA CAP 638. Additionally, the guidelines for standard operating and procedural elements within CAP 638 would also still be applicable.

4.2.4 CAA CAP 712. Micro-gravity flight operators should implement an effective SMS from the outset, especially as the flight activity is a non-standard profile. The interaction between management, flight crew, cabin crew and passengers will be more direct; a positive safety culture and high professional standards will be essential to prevent accidents or incidents.

4.2.5 CAA CAP 755. The SRG's Safety Plan [7] has recently introduced CAP 755 to cover Recreational Aviation Activities. The Safety Plan states:

'*There is a higher risk of personal injury when compared with a Public Transport flight. The marketing of some of these activities has changed significantly in recent years and a number of Recreational Aviation Activities are now available to the public. Some of these activities pose significant safety risks to the participants. The concept of a recreational aviation activity revolves around permitting the general public to partake as passengers, whether for payment or not, in an activity that cannot meet the Public Transport standards*'.

Micro-gravity flights could fall under the Recreational Aviation Activity caveat and as such, CAP 755 provides the necessary additional guidance for Operators in developing RAA Manuals.

4.3 Airspace Policy.
As the aircraft will be certified and have standard Navigational Aids, normal ANO rules will apply. The flights will nominally be conducted between FL200 and FL320 (about a 10,000ft altitude block is required), within Class C airspace, therefore separate Temporary Reserved Areas (TRA) may be appropriate. Indeed, the Zero-G corporation use an FAA-designated corridor of 100nm long and 10nm wide [5] as part of their safety

mitigation.

5. Aircraft Considerations

5.1 Hydraulics.
Modified hydraulic systems were found to be the main consideration in order to prevent cavitation during the parabolic manoeuvre; this may not be applicable to all aircraft types.

5.2 Other Systems.
Other aircraft systems would have to undergo a verification analysis in order to satisfy the requirements. Systems in this category could include engines, fuel, oil (including self-contained systems such as Powered Flying Control Units, Artificial Feel Units and Stall Protection System).

5.3 Aircraft Structural Integrity.
During Flight Testing, strain gauges can be applied and monitored to provide assurance that the specific type of aircraft design can cope with the parabolic manoeuvres. Accelerometers are required for visual reference of gravitational force for the pilots to ensure they do not exceed the aircraft's limitation and to ensure the correct amount of gravitational force is being applied according to the Flight Director's profile [8].

5.4 Flight Director.
A pre-programmed flight director for each parabola profile would aid the pilot in carrying out an efficient and safe manoeuvre. This would also be a safety mitigation strategy.

5.5 Cabin.
The cabin configuration needs to be adapted to provide a normal phase of flight compartment with standard regulatory seating and emergency arrangements (oxygen, and emergency lighting and escape). The zero-g 'experiential compartment' should be specifically designed for safety:

5.5.1 Padding requirements. FAA standards require 1.5inch minimum cushioning protection.

5.5.2 Lighting. Emergency lighting will have to built integral to the compartment and perhaps be aligned on the sidewall.

5.5.3 Handholds. Steadying handles along the floor, side and roof will be required to help the participants.

6. Crew Considerations

Flight Crew and Cabin Crew will both require specialist training in performing micro-gravity flights as part of a Recreational Aviation Activity. The Flight Testing process will have provided the pilots with invaluable experience and once certified, they will be able to hone their parabola manoeuvre skills with a comprehensive training package. This will also allow the Cabin Director and cabin crew to train in a real-time environment, post simulated and theoretical ground training.

7. Experience versus Experiments

This paper has discussed the certification and operational aspects from a purely human experiential point of view as a one-off recreational activity or as part of a pre-qualifying commercial spaceflight training programme. Scientific experiments can be conducted and the extra safety precautions regarding the equipment and tests would be required, as mentioned in 3.2.4.

8. Recommended Approach

To anticipate the requirements of future commercial spaceflight training and general recreational activities, it is recommended that the CAA take the lead in implementing policy, strategy and guidelines for micro-gravity flights, not only for the UK, but on a pan-European level.

8.1 Micro-gravity Flight CAP.
Top-level CAA oversight is required and a unique Micro-Gravity CAP could be introduced by the CAA, in conjunction with EASA, to provide specific guidance for operators, regarding the regulatory, continued airworthiness and safety management requirements.

8.2 Regulations.
An Operator's selected aircraft should undergo the necessary modifications and flight test regime as part of the certification process. The aircraft would then be certified under normal code of airworthiness standards, with the likelihood of an STC and/or AAN being awarded. TRAs (M – for Micro-Gravity) could be assigned for the flights (rather than individual applications for special events & unusual aerial activity).

8.3 Continued Airworthiness.
Along with standard continued airworthiness for the baseline aircraft certification, additional measures will be required on the modification aspects; hydraulics, accelerometers, flight director and the cabin module (lighting, handles and padding).

8.4 Safety Management.
Operators should employ an effective safety management system (CAP 712) and could adopt an operational safety case approach due to the additional complexities with the modifications, verifications, continued airworthiness, training and competencies. These additional factors will need careful consideration and management:

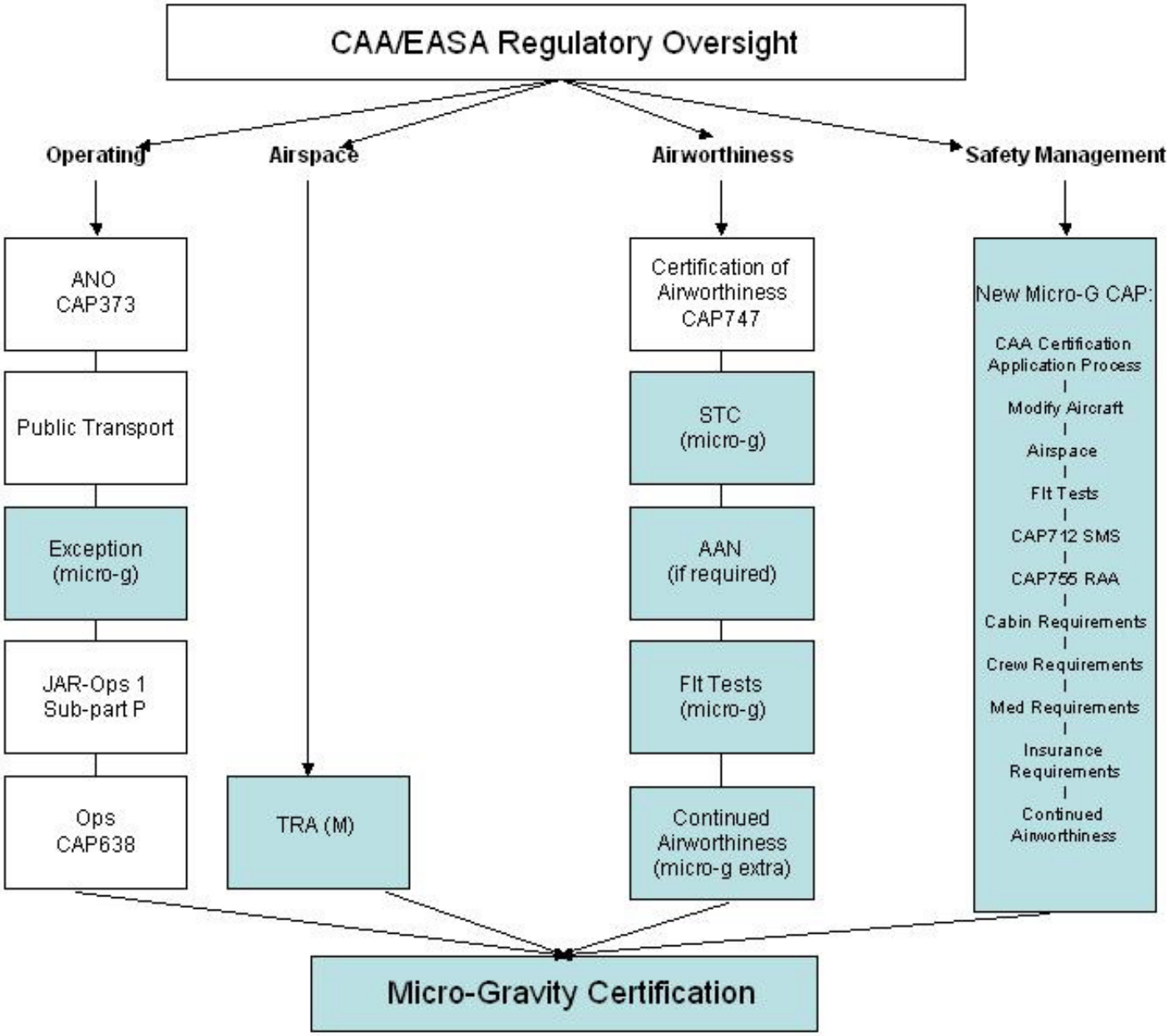

Figure 2: Summary of Recommendations – The white boxes indicate existing CAA criteria and the blue shaded boxes indicate the suggested process for micro-gravity certification.

8.4.1 Operations. CAP755 should be used as a guide for their operations and for producing an auditable manual.

8.4.2 Cabin Safety. Safety within the cabin will be a high priority for operators and a competent and qualified Cabin Director should be appointed. This position would be a supervisory role over the passengers, and training coaches (for co-ordinating the weightlessness activities) in conjunction with the flight-deck instructions for the parabolic manoeuvres.

8.4.3 Medical Requirements. During the flight, g-forces no greater than rollercoaster ride will be encountered, therefore a medical questionnaire should suffice for participants taking only a micro-gravity flight.

8.4.4 Insurance Requirements. The operator is bound by the Civil Aviation (Insurance) Regulation 2005, 1089 [9] to carry insurance. In America, Insurance Waivers are also required by the passengers, saying that they understand the risks involved; this would not be applicable within UK and EASA. Instead, as well as the operator's insurance, a contracted in-flight individual insurance could be appropriate from a participant's perspective.
The recommendations have been summarised in Figure 2, above.

9. Conclusions

The goal of this paper was to examine the certification and operating requirements of current micro-gravity flight operators and recommend appropriate solutions for these flights to be carried out in the UK. The Zero-G FAA commercial certification process was examined versus U.S. governmental and French partial-governmental methods.

It is considered that the CAA could certify the aircraft and operators under normal code of airworthiness

standards with an additional Supplementary Type Certification for the modification approval. This could be carried out under the EASA remit; thereby the UK would be leading the way in the introduction of commercial spaceflight training and micro-gravity flights for recreational aviation activities. The Airspace department could then nominate TRAs or suitable corridors for micro-gravity operators, whereby Flight Testing could commence.

The SRG could then introduce a unique Micro-Gravity CAP whereby Operators would be given advice on the safe operation of their activity, using current CAPs (CAP 373, CAP 747, CAP 638, CAP 712, CAP 755), and given additional advice on aircraft requirements, crew considerations, cabin safety, medical and insurance requirements.
It is concluded that commercial Micro-Gravity flights could be undertaken within the UK, and indeed European, airspace following the introduction of UK and EASA regulations and guidelines.

10. References

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[2] Manual – 'Parabolic Flight with A300 Zero-G: Users Manual', Edition 5.2, Novespace, France, 1999

[3] http://www.nasa.gov/audience/forstudents/5-8/features/F_Astronaut_Journals.html

[4] http://www.novespace.fr/VEnglish/Microgravity_a/microgravity.htm

[5] http://www.gozerog.com/home_full1.aspx

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[7]http://www.caa.co.uk/default.aspx?categoryid=978&pagetype=90&pageid=6289

[8] Paper – Hosman R J A & Kunen R C, Flight Director Guidance throughout the Parabolic Manoeuvre, A.M.S. Consult (e-mail rhosman@amsconsult.demon.nl)

[9] http://www.opsi.gov.uk/si/si2005/20051089.htm