Pulmonary Impairment in Sedentary Transit Operations at Low Altitude (PISTOLA): An Operational Study of Long-Haul Flight Effects

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PULMONARY IMPAIRMENT IN SEDENTARY TRANSIT OPERATIONS AT LOW ALTITUDE (PISTOLA): AN OPERATIONAL STUDY OF LONG-HAUL FLIGHT EFFECTS

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14. ABSTRACT-

An operational study was performed to replicate previous findings indicating pulmonary decline across long missions in a confined cockpit. Ten subjects completed a 12-hour simulated sortie in a model cockpit situated inside a hypobaric chamber maintaining 8000-foot equivalent altitude pressure. While situated in the cockpit, subjects performed simulated flight tasks at intervals, read, watched videos, and were offered refreshment and nourishment as desired. Subjects were administered Pulmonary Function Tests before and after the event, including recovery up to one hour after the flight.

COVID delays, medical DQ and attrition truncated the study from its planned sample size of 15, so parametric analyses were deferred to accommodate adding future participants, if resources and circumstances permit, to reach the planned sample size. For this reason, the Results section reports only the configuration of marginal means to date: Pulmonary metrics including Forced Vital Capacity (FVC), Forced Expiratory Volume: First Second (FEV1), and Peak Expiratory Flow (PEF) showed mean decreases of 3.3%, 1.9%, and 3.8% respectively from levels recorded before flight. FEV1/FVC ratio showed no evidence of systematic decrease. Decreases do not disconfirm the hypothesis that long missions in confined spaces reduce pulmonary capacity, but variance is wide relative to the magnitude of mean differences. This empirical question can be resolved more definitively in future pending the addition of more subjects to fulfill the planned sample size and statistical power. Investigators are pursuing resources to accomplish this follow-on effort.

15. SUBJECT TERMS- Pulmonary Function Test, PFT, FVC, FEV1, PEF, Vital Capacity, Expiratory Flow.

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1.0 EXECUTIVE SUMMARY

1.1 Introduction

An operational study was performed to replicate findings obtained in a previous study (Beer et al. 2017) that indicated declines in measured pulmonary capacity across the course of a long mission in a confined cockpit. The objective was to determine whether the simulated mission would cause declines in metrics of pulmonary capacity, as had occurred in the earlier study.

1.2 Methods

Ten subjects completed a 12-hour simulated mission in a model fast-jet cockpit situated inside hypobaric Chamber E of the Brooks Aerospace Environment Protection Laboratory. Subjects were administered Pulmonary Function Tests (PFTs) before and after the event including recovery up to one hour after the flight.

Before the simulated mission, each subject donned aircrew flight equipment (AFE) and entered the model cockpit where he or she was placed in an aircrew harness. A PFT battery was administered, which generated the pulmonary metrics FVC, FEV1, PEF and FEV1/FVC among other indices. The chamber was then brought to an 8000-foot equivalent altitude pressure, which was maintained for the next 12 hours as the subject stayed in the cockpit continuously. Throughout the mission, the subject performed a minimally demanding simulated piloting task at intervals, interspersed with idle periods which the subject could spend reading or watching videos or films. Nourishment (tube food) and liquid refreshment were provided as requested throughout the flight. After the 12-hour mission time elapsed, the chamber was returned to ground-level pressure and the subject was administered the PFT battery. The subject was returned to the cockpit for PFT testing 15 minutes after the end of the mission and then again 60 minutes after the end of the mission.

1.3 Results

COVID delays, subject attrition and medical disqualifications truncated the study from a planned sample size of 15 to the actual sample of ten to date. Across the course of the mission, subjects exhibited mean declines in FVC, FEV1, and PEF of 3.3%, 1.9%, and 3.8% respectively from levels recorded before flight. The low N yielded relatively wide variance relative to mean differences, however, which reduced the statistical power of the study. For this reason, investigators have deferred comprehensive parametric analyses which, once performed, would preclude the inclusion of additional subjects to fulfill the original planned sample size.

1.4 Conclusions

The study largely fulfilled its objective of recording pulmonary capacity across the course of a long, confined mission, but the lower-than-planned sample size reduced statistical power for the planned analyses. The decreases in the FVC and PEF metrics of pulmonary capacity do not, as yet, disconfirm the hypothesis that long missions in confined spaces could reduce pulmonary capacity. It is hoped that it will be possible to secure resources in future to complete or surpass the original planned sample and answer this empirical question definitively.

2.0 INTRODUCTION

A recent study examining fatigue in the operational environment of the U-2 aircraft yielded a potentially influential finding: the recorded pulmonary capacity of physically fit subjects declined across a 12-hour simulated mission in a confined cockpit under hypobaric altitude conditions (Beer et al., 2017). At the end of the mission, subjects' recorded forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), peak expiratory flow (PEF), and FEV1/FVC ratio decreased significantly. This occurred in both an experimental condition in which subjects wore a full pressure suit and breathed 100% oxygen, and a comparison condition in which subjects wore aircrew flight equipment (AFE) and breathed air. It was concluded that one plausible explanation for the recorded decrease in pulmonary capacity was because of the limited mobility imposed by the mission. Another plausible explanation for the finding was that since the pulmonary function tests (PFTs) were conducted in slightly different locations before and after the simulated mission (viz. in an office chair outside the cockpit before the test flight vs. in the cockpit seat after the flight), this could have affected capacity measurements.

Potential loss of pulmonary capacity presents a concern that could afflict any operational community whose members complete long missions in confined quarters or experience periods of constrained mobility. Such communities include air-evacuation medics, long-haul pilots, and expeditionary personnel required to remain stationary and unobserved. The potential for pulmonary decline, moreover, could have profound implications for patients during and after long-haul transit.

Previous investigations examining the effect of inactivity on pulmonary capacity are, perhaps surprisingly, relatively scarce. The few studies extant examined pulmonary performance in subjects experiencing bed rest in research settings (some with altitude exposure and some without) or enforced inactivity in a hospital environment. Loeppky et al. (1993), reporting that the combination of head-down bed rest and mild hypoxia reduced oxygen uptake, attributed the decline to inactivity. Similarly, a variety of bedrest and tilt conditions configurations have yielded a similarly varied spectrum of pulmonary effects including reductions in maximal mid-expiratory flow (Montmerle et al., 2002), FVC, FEV1, and PEF (Galanis et al., 2013). Suesada et al. (2007) determined that five days of hospitalization diminished FVC and inspiratory and expiratory pressure even in patients who were not restricted to bed rest. This last finding is perhaps most relevant to the goals of this project since it concerns physiological effects of relative inactivity in a normal gravitational environment.

This study was performed to replicate the mission conditions of the previous study and repeat PFT recordings using a more uniform procedure and a better-calibrated spirometer instrument. To that end, subjects completed a 12-hour simulated mission (hereinafter also referred to as a "test flight") in a high-fidelity model of the U-2 cockpit, situated in a hypobaric chamber which was held at an ambient pressure equivalent to 8000-foot altitude (a relatively low altitude which represents cabin conditions in commercial and many air-evacuation flights). The model cockpit, equipment specification, and scheduling of tasks and activities permitted for the subjects all duplicated as closely as possible the AFE condition in Beer et al. (2017). The original test design was augmented in three ways: first, greater procedural uniformity was achieved by performing all PFTs in the same operational configuration: the subject was tested both before and after the mission while seated in the cockpit wearing AFE and an aircrew harness. Second, a

more advanced spirometer was employed for PFT measurements. Third, additional PFT cycles were administered 15 minutes and one hour after the end of the mission, to assess subjects' recovery from any potential decline in pulmonary capacity.

In recognition of the objective to determine whether a 12-hour period of relative inactivity in a confined cockpit induces measurable pulmonary decline, the study tested one hypothesis, namely that indices of pulmonary capacity including FVC, FEV1, PEF, and FEV1/FVC will be significantly lower after the simulated mission.

3.0 METHODS AND PROCEDURES

3.1 Subjects

Ten non-smoking volunteers aged 21-40 (nine males, one female) participated after enrollment which was documented according to informed consent principles. Subjects were active-duty U.S. Air Force personnel who were members of the Brooks High-Altitude Research Subject Panel or the Brooks G-Acceleration Research Subject Panel, which require a general physical examination including pulmonary evaluation as prerequisite for participation. As part of their enrollment, subjects completed a PFT training battery to learn how to perform the test; data from this initial test cycle were also used as a screening device to identify subjects with potential restriction, obstruction or other pulmonary conditions that could preclude participation. Two subjects wore vision correction.

The study was planned to employ 15 subjects, but logistical and administrative setbacks emerged to delay its completion. Challenges included delayed arrival of funds, a COVID lockdown on research activity imposed in early 2020, and subsequent attrition in the Brooks Altitude and Acceleration Research Panels. Upon termination of the study, 13 of the planned 15 subjects had been enrolled. Of these, two were lost to medical disqualifications (MDQ). One subject experienced symptoms akin to decompression sickness for reasons unrelated to this study and dropped off the Altitude Research Panel. A second subject withdrew following the practice PFTs administered on enrollment; this subject exhibited a low FEV1/FVC ratio, his enrollment was reviewed by a pulmonology specialist at San Antonio Military Medical Center (SAMMC), and he was withdrawn as a precautionary measure. One additional subject was lost to attrition, as he failed to maintain contact with research schedulers to complete the study. This left an N of ten upon termination of the study.

The experimental protocol for this study was reviewed and approved by the Institutional Review Board of the Air Force Research Laboratory 711th Human Performance Wing (AFRL 711/IR).

3.2 Flights

Simulated missions were conducted in a model cockpit which duplicates the internal and external dimensions of the U-2 aircraft (Sage Cheshire Aerospace, Lancaster CA). The cockpit features a flight seat, pilot harness and canopy which all resemble closely those in a real U-2 (Figure 1). It incorporates a Hyundai P224W LED monitor (1680x1050 pixels; 52x41 deg) for the piloting display and Thrustmaster® Warthog flight controls. We note that these flight controls differ from the yoke-based controls in the real U-2 and were selected for our research applications because they facilitate novice training. The model cockpit was situated inside hypobaric Chamber E of the Brooks Aerospace Environment Protection Laboratory. In the enrollment session, subjects

were given training to familiarize them with the task requirements for the test flight. This included practice PFTs as stated above, and a synthetic piloting task as used in the original study (Beer et al. 2017). In the flight task training, subjects were introduced to the flight controls in the model cockpit and trained to follow a straight-and-level simulated flight path maintaining constant altitude, indicated airspeed, and heading. The flight task was implemented using the XPlane simulation suite (Laminar Research, Columbia SC) and was included to duplicate the demands in the first study and to serve as one available activity to keep the subject awake and mentally engaged throughout the long test flight. The task was presented for 30-minute periods at odd-hour intervals (at the start of the flight, then at hours 3, 5, 7, 9 and 11 throughout the flight). The flight task is not considered further in this report, as subjects did not train extensively on it and the study objective was to measure pulmonary capacity, not piloting proficiency.

Fig. 1. Model cockpit for PISTOLA test flights.

Subjects were given guidelines to follow a low-fiber diet for 48 hours before the test session, as practiced by operational U-2 pilots. Subjects were instructed to sleep at least seven hours and avoid alcohol or excessive caffeine (defined as more than one cup of coffee or caffeine drink) in the day before testing, and to forego participation if they were not well rested.

On the day of the test flight, the subject reported to the Research Altitude Chamber facility at 0700 and was examined by the Medical Observer to confirm his or her fitness for participation. The subject donned AFE including an emergency vest, g-suit, and parachute

harness. Subjects did not wear a helmet or respiration equipment; they breathed ambient air (21% O2) throughout the mission. The subject was then escorted to the chamber. A 5000-foot-equivalent altitude "ear and sinus check" was performed to verify that the subject was not experiencing complications associated with ear or sinus blockage. The subject was permitted to take a rest room break and was then situated in the cockpit seat. As in the prior study, the harness and seat straps were employed, with a loose, comfortable fit verified by placing a fist between the harness and the sternum.

The PFT was then administered several times consecutively with the subject in the cockpit seat (see below). The flight commenced after the initial administration of the PFT: the chamber was brought to an altitude pressure equivalent to 8000 feet above mean sea level and held at that ambient pressure for 12 hours, during which time the subject remained in the cockpit continuously. Chamber pressure ascents and descents were executed at 5000 ft/min unless the subject experienced sinus pain upon descent, in which case descent rate was reduced. An inside observer accompanied the subject to altitude and remained in the chamber to provide food and refreshment and administer any other safety support or aid required throughout the flight.

As in the original study, lower leg exercises were employed every two hours to maintain circulation (Arya et al., 2002; Bagshaw et al., 2001); although this task renders the immobility of cockpit confinement incomplete, it was performed for subjects' well-being and to replicate the original procedure. Exercises were performed five times for each leg: first, the subject straightened and then flexed at the knee; then the subject flexed and then extended the ankle; then the subject rotated the foot clockwise and then counterclockwise about the ankle.

A Lake Louise survey (Roach et al., 1993) was administered at the four-hour and the eight-hour time point, to confirm the subject was not experiencing acute mountain sickness (AMS). Medical support was available from a Medical Observer throughout the flight.

The time course of the test flight (Figure 2) incorporated the tests and activities named above, to include PFT (immediately before, immediately after, 15 minutes after, and one hour after the end of the flight), simulated flight task (six half-hour virtual sorties performed at two-hour intervals), lower leg exercises (performed at two-hour intervals), and the AMS survey.

	Pre-Flight	Hour 0	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H12+15min	H12+1hr
chamber event		Ascent to 8000 feet												Descent to GL		
pulmonary testing		PFT												PFT	PFT	PFT
medical monitoring and exercise	Medical Approval			Lower-Leg Exercises		Lake Louise Survey; LL Exercises		Lower-Leg Exercises		Lake Louise Survey; LL Exercises		Lower-Leg Exercises		Medical Eval		Medical Release
cognitive activity			FSPT	Movies, Reading or Games	FSPT	Movies, Reading or Games	FSPT	Movies, Reading or Games	FSPT	Movies, Reading or Games	FSPT	Movies, Reading or Games	FSPT			

Fig. 2. Time course of a PISTOLA test flight.

In the intervals between performing the above tasks, the subject was permitted to watch videos or movies, read, or play computer games on a tablet. The subject was not permitted to sleep or to send or receive social media content, texts, emails, or telephone calls.

Tube food and drinks (water, non-caffeinated beverages, or sports drinks) were provided as desired throughout the flight. A urinary collection device was available as necessary.

After 12 hours, the chamber was returned to ground level pressure at 5000 feet/minute. Upon arrival at ground level, the subject completed the post-flight PFT immediately while still

seated in the cockpit, according to the same procedure as before the flight. The subject was then extracted from the cockpit and was examined by the Medical Observer to verify well-being.

The subject was then permitted to stretch, visit the rest room, or enjoy liquid refreshment. Fifteen minutes after the arrival at ground level pressure, the subject was again situated in the cockpit, where the first recovery PFT measurements were accomplished. The subject was then extracted from the cockpit again and was given the opportunity to move around, visit the rest room, exercise gently, or enjoy liquid refreshment until one hour after the arrival at ground level pressure, at which time he or she was returned to the cockpit and the final, one-hour recovery PFT measurements were performed. The subject was then released.

3.3 PFT and Test Equipment

PFTs were performed using a handheld, standalone MIR Spirodoc spirometer (Medical International Research, Rome, Italy) which includes an internal temperature sensor to implement temperature, ambient- and water vapor pressure (BTPS) correction. The spirometer was calibrated before each test event using a MIR 3L calibration syringe to a volume accuracy within +/- 1%. In the previous study, PFTs were performed three times before and after the twelve-hour test flight, so the replication here recorded the first three test cycles as a minimum. If PFT cycles were deemed inconsistent, defined by FVT or FEV1 readings differing by more than 0.150L, additional cycles were performed until three readings were obtained within this volume criterion (Graham et al., 2019). The metrics FVC, FEV1, PEF, and FEV1/FVC ratio are reported here.

All PFTs, including pre-mission, immediately post-mission, 15 minutes, and one hour post-mission were conducted under similar conditions in the cockpit seat. Personnel administering PFTs completed procedural training by a certified respiratory technician from the 59th Medical Wing under the supervision of an MD pulmonologist from SAMMC.

A disposable turbine (MIR) and nose clip were provided to each subject. Subjects were instructed to block their nose and lock their lips around the turbine. When ready, subjects were coached to take a maximal inspiration, then expire as quickly as forcefully as possible and maintain exhalation throughout a duration of at least six seconds. When prompted by the spirometer and coach, subjects took another maximal inspiration before resting between trials. Trials were completed when three acceptable measures were taken within 0.150L for FVC and FEV1 values (Graham, 2019). For each set of tests, a maximum of 8 trials were performed in each PFT test cycle.

3.4 Statistical Design

Data were recorded and configured according to a repeated measures design with one independent factor called Time, with four levels: $T_{pre\text{-}}$; $T_{post\text{-}}$; $T_{post+15min}$; and $T_{post+60min}$. Dependent measures include FVC, FEV1, PEF, and FEV1/FVC ratio. The planned analysis instrument comprises a one-way within-subjects analysis of variance, to be performed using SPSS Version 19. A planned comparison will contrast each dependent measure recorded immediately post- vs. immediately pre-flight.

Since the study did not reach its full enrollment, these parametric analyses were deferred to accommodate the possibility that additional resources can be secured to fulfill the projected sample size and statistical power in the near future. (Completing parametric analyses now would preclude the inclusion of additional subjects later.) For this reason, the Results section reports only the dependent measures' marginal means and standard errors of the mean to date.

4.0 MAJOR EVENTS/MILESTONES/SUCCESS

- Ten successful test flights were conducted, from which were generated a summary dataset representing PFT metrics before and after a 12-hour simulated cockpit mission.
- The subject pool was expanded to include the Brooks G-Acceleration Panel in addition to Brooks High-Altitude Panel; this partially enabled study to catch up to its schedule and planned sample size.
- Exploratory data analysis was performed to characterize qualitative trends in pulmonary capacity: trends indicate decreases in mean FVC and PEF.
- This indicates a need to fulfill the planned sample to test more definitively whether long cockpit missions reduce pulmonary capacity.

5.0 RISK ASSESSMENT

5.1 Risk Analysis

Following completion of this project, the only risk component that remains is that of drawing a precipitate conclusion regarding the effect of sedentary operational conditions on pulmonary capacity. Drawing an erroneous conclusion that sedentary conditions reduce pulmonary capacity would constitute a Type I error that could lead to the adoption of incorrect and potentially wasteful operational procedures. Conversely, missing this potentially meaningful finding could allow the conduct of missions that might compromise performance and health of aircrew and other operators in challenging environments. Investigators plan to address this by pursuing follow-on resources to fulfill the planned complement of research subjects.

5.2 Technical Challenges

The study was hampered by administrative and COVID delays, the attendant scarcity of volunteer subjects from 2020 on, and by the loss of three volunteer subjects to medical disqualification and attrition.

6.0 TRANSITION PLAN

6.1 Military Relevance

Loss of pulmonary capacity could present a concern for operational communities whose members complete long missions in confined quarters or experience periods of constrained mobility. Such communities include air-evacuation medics, long-haul pilots, and expeditionary personnel required to remain stationary and unobserved. The potential for pulmonary decline, moreover, could have implications for patients during and after extended inactivity or transit.

6.2 Transition Strategy

The initial phase of knowledge transition from this project comprises pursuit of follow-on resources to fulfill the planned sample size as stated above, to determine more definitively whether the declines observed in PFT metrics to date are robust. Pending this outcome, the next objective will be to deliver a future research roadmap to determine the scope and physiological manifestations of pulmonary decline. Objectives will include: 1) use imaging techniques such as

electrical impedance tomography (EIT) to characterize the anatomical effects that might cause or pulmonary decline; 2) determine whether pulmonary decline occurs across shorter mission durations (e.g. one, four or eight hours); and 3) determine whether restoring mobility to the subject via exercise will attenuate the pulmonary decline.

Investigators will consult with pulmonary subject matter experts at SAMMC and 59MDW in concert with operational planners from the expeditionary and high-altitude special operations communities to determine the magnitude and operational implications of a single-digit decline in, for example, vital capacity or peak expiratory flow. If pulmonary decline is determined to be operationally meaningful, findings will be transferred via 59MDW to communities of interest, including particularly air-evacuation specialists, specific aviation communities such as transport (AFMC), JSF (F-35 SPO), U-2 pilots (9PSPTS), and operational communities with specialized high-altitude environmental requirements. Potential countermeasures will be translated and conveyed to military-medical communities of interest.

Table I. PFT Pulmonary Capacity Metrics: Means and SEs of the Mean, by Time

Metric	Pre-Flight	Immediate Post-Flight	Post+15Min	Post+1Hr
FVC, Liters	5.31 (0.28)	5.14 (0.29)	5.19 (0.32)	5.17 (0.34)
FEV1, Liters	4.23 (0.22)	4.15 (0.23)	4.15 (0.25)	4.19 (0.25)
PEF, Liters/Min	9.31 (0.54)	8.96 (0.42)	9.05 (0.48)	9.26 (0.40)
FEV1/FVC, Percent	79.9 (1.40)	80.9 (1.03)	80.2 (1.30)	81.0 (1.30)

Marginal means are shown with standard errors of the mean in parentheses.

7.0 RESULTS AND DISCUSSION

As stated, administrative and COVID delays, medical disqualifications and subject attrition truncated the study from a planned sample size of 15 to the actual sample of ten to date. This circumstantial truncation of the study reduced its statistical power and for this reason, investigators have deferred comprehensive parametric analyses to accommodate the possibility of pursuing follow-on resources to continue data collection, fulfill the original sample size, and restore statistical power.

Summary means to date for the dependent measures FVC, FEV1, PEF, and FEV1/FVC ratio are presented in Table I and Figures 3-6. Since our primary objective was to replicate the procedure and data collection practiced in the original U-2 study (Beer et al. 2017), we report here on the first three PFT tests recorded at each time point. Across the course of the mission, subjects exhibited declines in FVC, FEV1, and PEF of 3.3%, 1.9%, and 3.8% respectively from levels recorded before flight, as indicated via comparison between mean values recorded immediately post-flight vs. pre-flight.

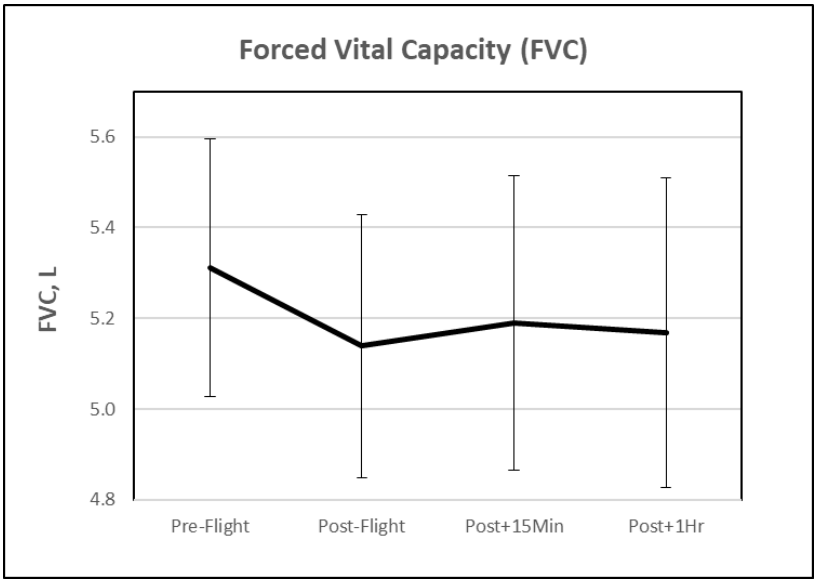

Fig. 3. FVC marginal means. Error bars depict SE(Mean).

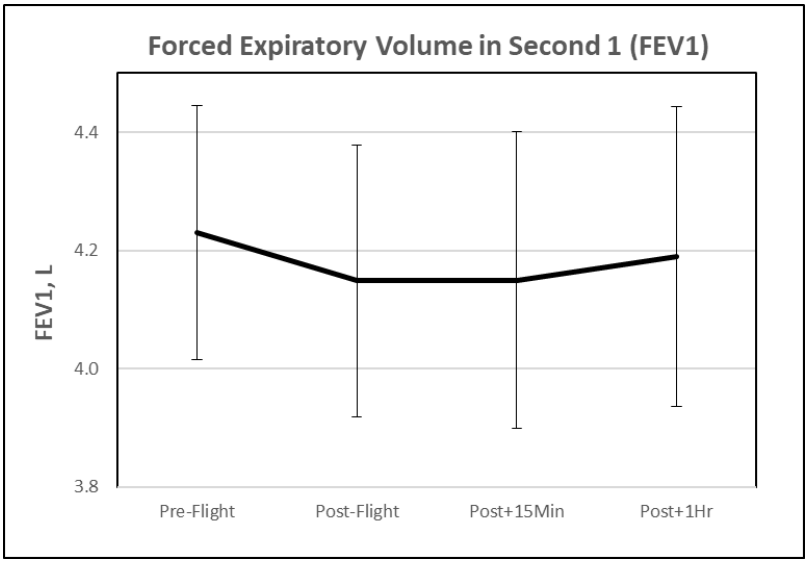

Fig. 4. FEV1 marginal means. Error bars depict SE(Mean).

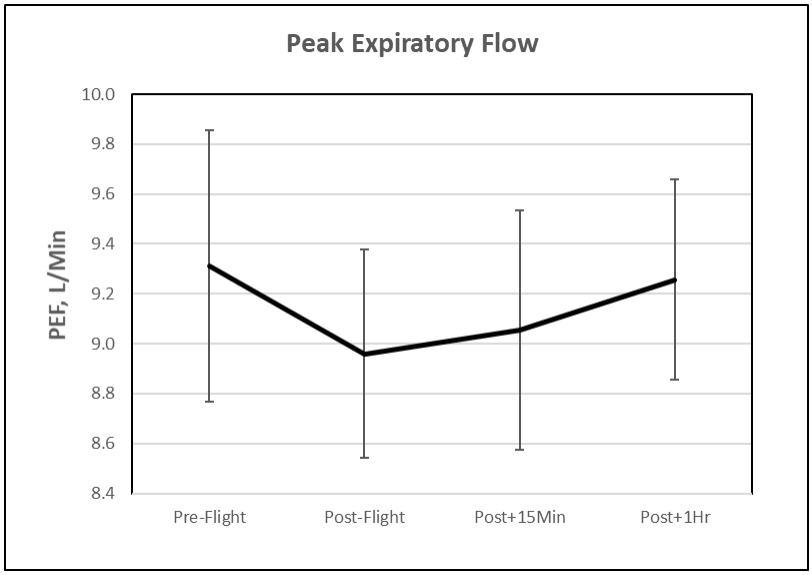

Fig. 5. PEF marginal means. Error bars depict SE(Mean).

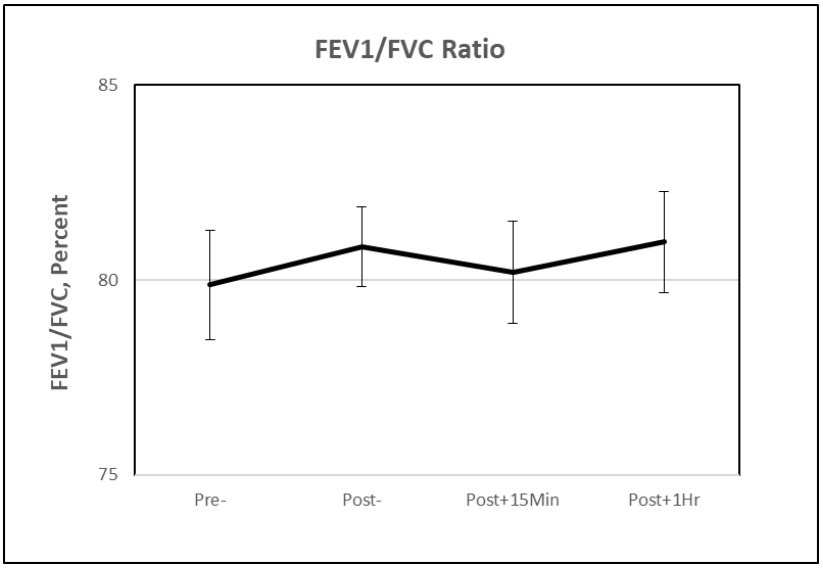

Fig. 6. FEV1/FVC Ratio, marginal means. Error bars depict SE(Mean).

The direction of decline in these metrics between the Pre-Flight and Post-Flight time points is consistent with the significant decrease reported for FVC, FEV1 and PEF in the original Beer et al. (2017) study. The ordinal progression of means over time suggests that of these metrics, PEF and FVC declined proportionately more than FEV1, a trend that tended to flatten the progression of the FEV1/FVC ratio. Of the four metrics, only FVC showed any indication of a decline persisting through the hour-long post-flight recovery period.

It is evident, however, that the lower-than-planned sample size yielded wide variance relative to differences observed in the marginal means. We emphasize that pending the potential addition of more subjects, the effect of Time on these PFT metrics has not yet been subjected to

parametric tests, and for this reason these trends cannot yet be considered conclusive evidence of pulmonary decline.

The FEV1/FVC ratio has historically been used as a clinical diagnostic instrument, with values below 0.70 proposed as indicative of chronic obstructive pulmonary disease (COPD). Applying this threshold as a fixed criterion has, however, been questioned as simplistic and vulnerable to false positive diagnoses of airway obstruction in apparently healthy patients, particularly those over the age of 50 (Swanney et al., 2008). FEV1/FVC was included in this study as a metric of individual pulmonary capacity over time as opposed to a diagnostic instrument. No systematic decline is evident in mean ratios recorded after the flight, which contrasts with the finding reported in the earlier study (Beer et al., 2017).

In evaluating the potential effects of environmental conditions on pulmonary capacity, we emphasize the value of empirical caution. As documented by Cooper (2005) and Graham et al. (2019), administering PFTs inconsistently or indifferently can yield variable measurements, and this added noise can compromise the accuracy and sensitivity of testing performed casually in operational conditions or in the workplace. Of particular concern, performance metrics can be unstable if the tester imposes inconsistent or tentative verbal instructions during testing, or the patient or test subject fails to expend maximal effort upon exhalation.

We note also that the research objectives of this study—to test whether pulmonary capacity and performance will decline in a subject who is confined over time wearing aircrew equipment that could impose restriction—differ somewhat from the clinical objectives of evaluating a patient's individual pulmonary performance, health, and absence of obstruction and restriction. The latter objectives are achieved via imposing clinical stability criteria, and procedural measures were implemented in this study to maximize the uniformity of test conditions. In contrast to the previous study, more rigorous control of postural conditions was imposed by conducting all tests, before and after flight, in the cockpit with AFE and harness worn. Investigators responsible for PFTs completed pulmonary test training and strived to encourage subjects' maximum effort as enthusiastically and consistently as possible. Finally, a more sophisticated spirometer than used in the previous study was employed, and this instrument was calibrated on the day of every test event.

Despite these measures taken to maximize the continuity and uniformity of conditions in the chamber over time, some fluctuation in chamber temperature and humidity was unavoidable, and this could have contributed noise to the dependent measures recorded at four separate time points (Graham et al., 2019). It is also possible that imposing clinical stability criteria could present a challenge to the study's research objectives, since some test subjects may require more attempts than others to deliver repeatable maximum-effort test cycles. If a subject requires additional test cycles and becomes fatigued, stability could potentially be achieved at the expense of maximal performance.

Notwithstanding these qualifications and potential limitations, the observed ordinal distribution of marginal means for FVC, FEV1 and PEF recorded immediate before and after the simulated mission in this study resembles that reported in the earlier study. These data begin to provide an overview of the potential declines in pulmonary capacity across the course of a long-duration simulated mission in a confined cockpit. The study's shortfall in statistical power can be remedied with a follow-on continuation to fulfill the planned sample size, at which point it will be appropriate to perform further parametric analyses.

8.0 CONCLUDING REMARKS

The study largely fulfilled its objective of recording pulmonary capacity across the course of a long, confined mission, but the lower-than-planned sample size reduced statistical power for the planned analyses. The decreases in the FVC and PEF metrics of pulmonary capacity do not, as yet, disconfirm the hypothesis that long missions in confined spaces could reduce pulmonary capacity. Pending the availability of additional subjects to fulfill the planned sample size, however, this replication of a recorded decline in pulmonary capacity remains incomplete. It is hoped that it will be possible to secure future resources to resume data collection, complete or surpass the original planned sample, and answer this empirical question more definitively.

9.0 DELIVERABLES

The project's deliverables to date comprise this technical report and the comprehensive dataset encompassing PFT metrics recorded from ten subjects before, immediately after, and during recovery from the 12-hour simulated mission. Pending availability of additional resources to fulfill the planned sample size, investigators plan to submit a manuscript to an appropriate peer-reviewed journal such as *Aerospace Medicine and Human Performance*. If additional resources are not found within a reasonable period following this report, investigators plan to complete parametric statistical analyses on the existing dataset and draft this manuscript using the resulting findings.

10.0 COST

The project was planned and executed in two one-year technical orders which were scoped at $215k and $262k respectively. Kickoff and continuation of the project were subject to administrative funding delays, but funds were obligated and expended *in toto* by the conclusion of the second period of performance at the end of CY22.

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List of Symbols, Abbreviations, and Acronyms

59MDW: USAF 59th Medical Wing
BTPS: Body Temperature, ambient Pressure, Saturated water vapor correction factor for inspired and expired breath
FEV1: Forced Expiratory Volume in Second 1
FVC: Forced Vital Capacity
PEF: Peak Expiratory Flow
PFT: Pulmonary Function Test
SE(M): Standard Error of the Mean
USAFSAM: US Air Force School of Aerospace Medicine