# Evaluating the Impact of Flight Hours on Pulmonary Function in Military Pilots

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**INTRODUCTION:** Military pilots are routinely exposed to environmental stressors such as hypoxia, dry air, and G-forces, which may affect pulmonary function. Although spirometry is performed regularly to assess flight fitness, the long-term effects of flying on lung function remain unclear.

**METHODS:** This retrospective study analyzed data from the Center for Man in Aviation of the Royal Netherlands Air and Space Force, encompassing two parts. First, all medical assessments from 2012 to early 2025 were reviewed to determine how often pilots were declared unfit to fly due to abnormal spirometry. Second, a Generalized Estimating Equation model was used to assess the effect of cumulative flight time, smoking status, and age on the forced expiratory volume in 1 s/vital capacity ($FEV_1$/FVC) ratio using data collected between 2012 and mid-2019 (before the adoption of standardized Z-scores).

**RESULTS:** Out of 9182 assessments, 3 pilots were deemed unfit to fly solely due to an abnormal spirometry. In the Generalized Estimating Equation analysis of 4558 assessments, flight hours showed a nonsignificant trend toward a positive, albeit clinically irrelevant, association with $FEV_1$/FVC. There was no significant difference between aircraft types or between former and never-smokers. $FEV_1$/FVC declined significantly with age and was significantly lower in current smokers compared to never-smokers.

**DISCUSSION:** Pulmonary abnormalities rarely led to unfit declarations and no evidence was found for a negative long-term effect of military flying on pulmonary function. Age and smoking status were significant predictors of $FEV_1$/FVC decline. These findings may inform future refinement of pulmonary assessment protocols for military pilots.

**KEYWORDS:** pulmonary function test, occupational medicine health surveillance, aviation.

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Military pilots operate in extreme environments, including exposure to hypobaric hypoxia, where reduced oxygen pressure at altitude can impair physiological function. For example, flying at 10,000 ft (approx. 3000 m) in helicopters may cause mild hypoxia, while a loss of cabin pressure above 15,000 ft (approx. 4500 m) in fighter jets like the F-35 can result in impaired performance and loss of consciousness.[1] In addition to hypoxia, pilots are routinely exposed to high G-forces, dry cabin air, ozone, and pressurized oxygen delivered through masks.[2–4] These stressors may provoke bronchial hypersensitivity, asthma exacerbations, or atelectasis (partial lung collapse), particularly in susceptible individuals.

Optimal pulmonary function is, therefore, critical to ensure operational performance and flight safety. Obstructive or restrictive pulmonary conditions may increase the risk of acute in-flight incapacitation, necessitating early detection and monitoring through regular assessments.[2] For context, 94% of NATO air forces perform pulmonary function tests at initial examination of a candidate and 56% at renewal examinions.[5] At the Center for Man in Aviation of the Royal Netherlands Air and Space Force, pilots undergo aeromedical examinations

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according to the Military Aviation Requirements—Flight Crew Licensing.[6] These include initial spirometry tests upon entry and follow-up assessments at regular intervals. In contrast, the European Union Aviation Safety Agency requires spirometry only at initial assessment or when clinically indicated.[7]

Spirometry measures the forced expiratory volume in the first second ($FEV_1$) and forced vital capacity (FVC), with their ratio ($FEV_1/FVC$) being a key indicator of airway obstruction. Since 2019, the Center for Man in Aviation has adopted a Z-score threshold of $-1.96$ to define abnormal values, corresponding to the lowest 2.5% of the population.[8] Previously, an unstandardized $FEV_1/FVC$ ratio with a cutoff of $<70\%$ was used, still often the standard in civilian guidelines.[9]

While the value of pulmonary screening at service entry is well established, there is limited evidence supporting the current frequency of periodic assessments during service. Existing literature demonstrates that pulmonary function, specifically $FEV_1/FVC$, naturally declines with age, and smoking accelerates this decline.[10–12] However, the potential long-term effects of cumulative flight exposure on pulmonary function remain largely unexplored.

This study aims to evaluate whether military flying contributes to long-term pulmonary decline by analyzing the relationship between cumulative flight hours and $FEV_1/FVC$ ratio. Additionally, it investigates the prevalence of pulmonary function as a reason for declaring pilots unfit to fly, thereby informing the relevance of periodic spirometry in aeromedical assessments.

## METHODS

This retrospective cohort study used medical data from the annual assessments of Dutch military pilots. Military pilots undergo annual or biannual aeromedical assessments according to Military Aviation Requirements–Flight Crew Licensing regulations.[6] The study complied with Dutch legislation on retrospective analyses and followed applicable data privacy regulations. No formal medical ethics approval was required.

The study comprised two parts. An electronic database containing pilot assessments from January 1, 2012 (the introduction of the electronic database), to February 18, 2025, was reviewed. Duplicate entries and nonpilot personnel were removed. The primary outcome was the number of assessments that led to an "unfit to fly" classification based on abnormal spirometry. The total number of assessments was counted, and the number resulting in an "unfit" declaration was recorded. This section of the analysis provides a descriptive overview of the prevalence and distribution of fitness disqualifications due to impaired pulmonary function.

For the second part, assessments between January 1, 2012, and July 19, 2019, were selected to ensure use of the unstandardized $FEV_1/FVC$ ratio (prior to Z-score implementation). Pilots were categorized into five groups based on aircraft type: 1) fighter jets (e.g., F-16, F-35); 2) fixed-wing aircraft (nonjet); 3) rotary-wing (helicopter); 4) student pilots; and 5) unknown aircraft type. Groups 4 and 5 were excluded from statistical analysis for (incomplete) follow-up data. Pilots could appear in multiple groups if their roles changed during the study period. Data with missing spirometry or using Z-scores instead of raw $FEV_1/FVC$ were excluded. All spirometry tests were conducted by trained medical professionals using standardized procedures. The primary dependent variable was $FEV_1/FVC$. Independent variables included aircraft category, cumulative flight time (hours), age, and self-reported smoking status (categorized as never, former, or current smoker).

Data were analyzed using IBM SPSS Statistics for Windows, Version 29.0. As our dataset did not meet the requirements for a repeated measures ANOVA, a Generalized Estimating Equation model was applied to account for repeated measures within individuals.[13] Age and flight hours were treated as continuous variables. The independent variables were aircraft category, age, flight time, and smoking status. Age and smoking behavior were expected to be confounders. Statistical significance was set at $P < 0.05$.

## RESULTS

From the beginning of 2012 to February 18, 2025, 9182 medical assessments were conducted for pilots flying fighter jets, fixed-wing aircraft (nonjet), rotary aircraft, and student pilots. In this period, 84 pilots were classified as unfit, of which only 3 pilots were considered unfit solely on their spirometry abnormality: one initial applicant with pulmonary emphysema was disqualified, the other two were deemed temporarily unfit and regained flying status after assessment of and treatment by a pulmonary physician.

For the second part of the study, 4558 data points of 697 individuals were used. Descriptive details on the population are displayed in **Table I**.

**Table I.** Descriptive Results.

| GROUP | *N* ASSESSMENTS | *N* FEMALE (%) | AGE (yr), MEDIAN (IQR) | $FEV_1$/ FVC-RATIO, M (SD) | FLIGHT HOURS, MEDIAN (IQR) | SMOKING | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | YES (%) | NO (%) | NEVER (%) |
| Fighter jets | 1121 | 1 (0.1) | 38.0 (31.0-45.0) | 78.8 (5.9) | 2350.0 (1447.5-3170.5) | 133 (11.9) | 191 (17.0) | 797 (71.1) |
| Fixed wing aircraft (non jet) | 1257 | 52 (4.1) | 46.0 (39.0-51.0) | 79.2 (6.0) | 4000.0 (2780.0-5335.0) | 117 (9.3) | 275 (21.9) | 865 (68.8) |
| Rotary wing | 2180 | 112 (5.1) | 36.0 (29.0-45.0) | 79.6 (5.7) | 1950.0 (931.3-3265.0) | 339 (15.6) | 350 (16.1) | 1491 (68.4) |
| Total | 4558 | 165 (3.6) | 38.0 (29.0-47.0) | 79.5 (6.0) | 2264.0 (900.0-3651.0) | 589 (12.9) | 816 (17.9) | 3153 (69.2) |

Age and flight hours were distributed nonnormally and, therefore, are presented as median [interquartile range (IQR)]. $FEV_1/FVC$ ratio was normally distributed and presented as mean (SD).

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Age and flight hours were considered non-normally distributed and pulmonary function was normally distributed. A linear Generalized Estimating Equation model was built to examine the effect of the three pilot categories, age, and flight hours on pulmonary function, with a Quasi-likelihood under the Independence Model Criterion (QIC) of 148,914.440 and a marginal $R^2$ of 0.27.[14,15] Flight hours approached a statistically significant, but very small, positive effect [$B \approx 0.000$, $SE = 0.0002$, Wald $\chi^2(1) = 3.22$, $P = 0.073$]. However, age was significantly negatively associated with pulmonary function [$B = -0.17$, $SE = 0.04$, Wald $\chi^2(1) = 15.83$, $P < 0.001$]. This model is displayed in **Fig. 1**.

There was no significant difference in pulmonary function between pilots of fighter performance jets [$B = -0.78$, $SE = 0.53$, Wald $\chi^2(1) = 2.21$, $P = 0.137$] or fixed-wing aircraft [non-jet; $B = -0.13$, $SE = 0.57$, Wald $\chi^2(1) = 0.05$, $P = 0.823$] compared to rotary-wing pilots. These have been plotted in **Fig. 2**, panels A–D.

Smoking status was a significant predictor. Specifically, current smokers had significantly lower pulmonary function than never-smokers [$B = -1.51$, $SE = 0.58$, Wald $\chi^2(1) = 6.83$, $P = 0.009$], while former smokers did not differ significantly from never-smokers [$B = 0.23$, $SE = 0.54$, Wald $\chi^2(1) = 0.18$, $P = 0.674$]. There were no signs of effect modification (e.g., an interaction between age and smoking status on pulmonary function). Sex was initially examined for its potential effect, but as it showed no significant impact, it was excluded from the final model.

## DISCUSSION

This study explored the long-term effects of military flying on pulmonary function by analyzing over 4500 spirometry assessments and evaluating their association with flight hours, age, and smoking. The findings suggest that cumulative flight hours do not significantly impact $FEV_1/FVC$ ratios. In contrast, age and current smoking status were significantly associated with pulmonary function decline, confirming earlier findings.[10–12]

Only 3 pilots out of more than 9000 assessments were declared unfit to fly solely due to pulmonary abnormalities—1 initial applicant definitively and 2 of whom were only temporary, as they were able to resume flying after consulting with a pulmonary specialist—indicating that pulmonary disease is very rare among military aviators, which is in line with previous studies.[16,17] These results support the notion that, while initial pulmonary screening is important for flight safety, repeated spirometry during service may yield limited additional value, particularly in nonsmoking pilots. This is reflected in the number of NATO Air Forces that perform pulmonary function tests at initial examination (15/16) and at renewal examinations (9/16).[5]

Perhaps even more relevant from an occupational medicine perspective are the findings that the type of airframe does not seem to affect pulmonary function. While pilots of fighter jets are more exposed to altered ambient pressures or straining maneuvers, this does not seem to have a negative effect over thousands of flight hours. We feel this indicates that the pilots'

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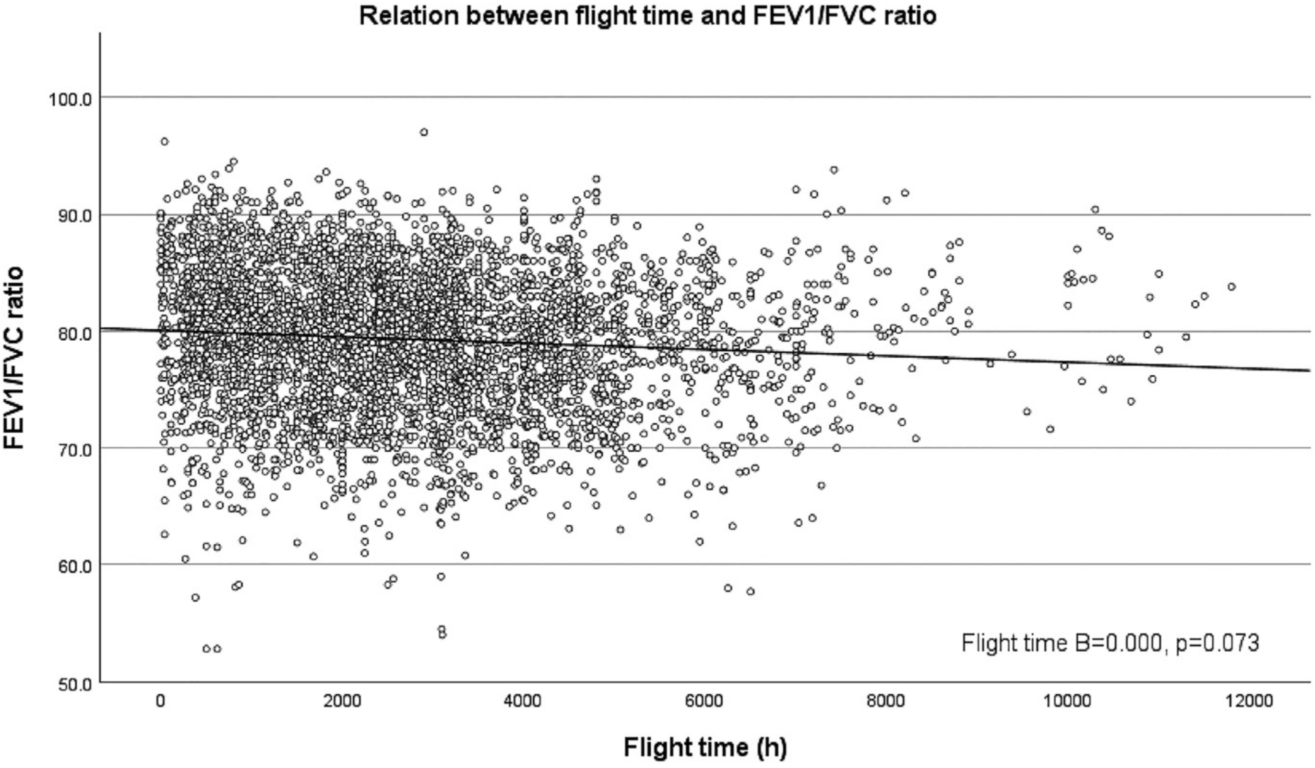

**Fig. 1.** Relation between flight hours and $FEV_1/FVC$ ratio. Each dot represents an assessment. The decrease over hours in $FEV_1/FVC$ ratio cannot be attributed to flight hours ($B = 0.000$, $P = 0.073$) but is the result of ageing ($B = 0.17$, $P < 0.001$), which is displayed in Fig. 2D.

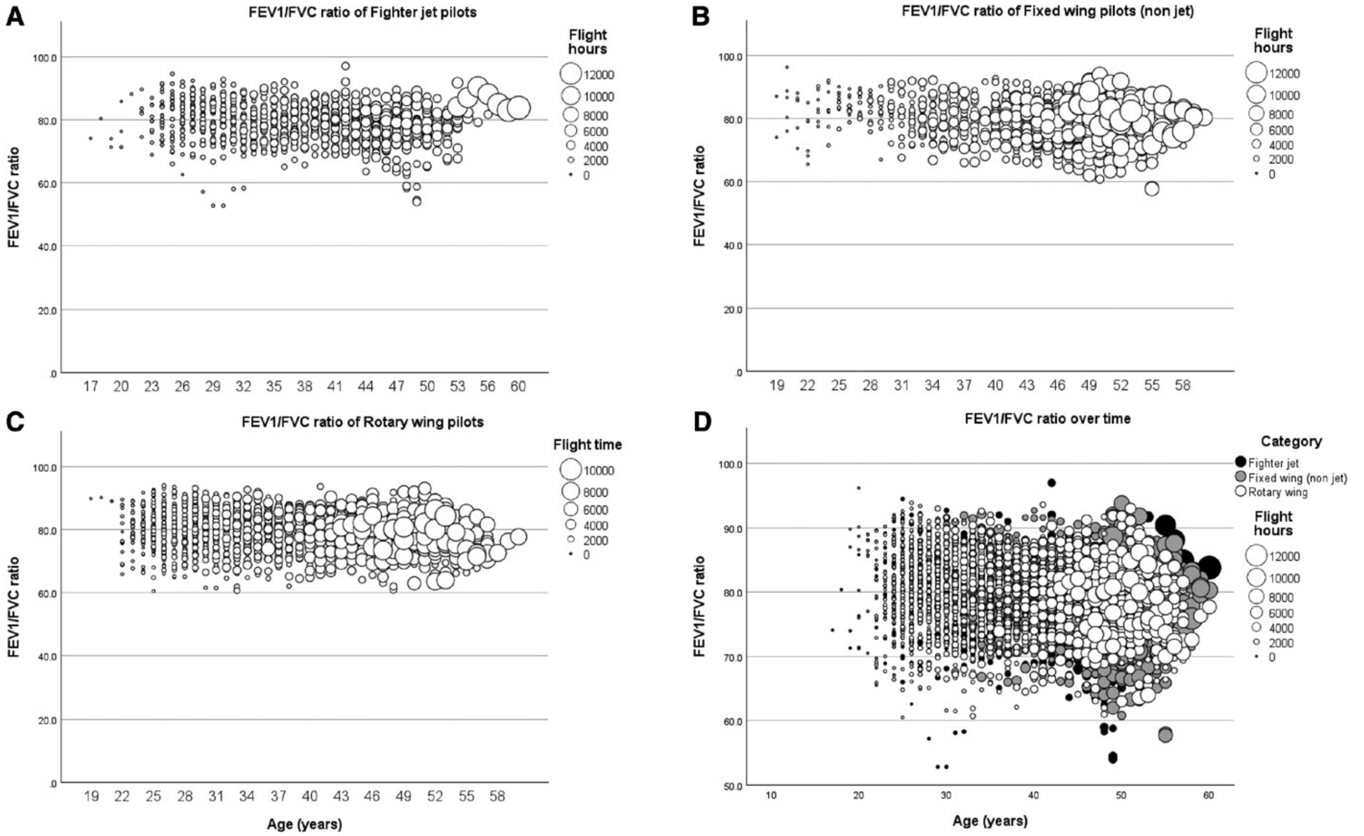

**Fig. 2.** Relation between age and $FEV_1/FVC$ ratio. A) Scatter plot of pulmonary function ($FEV_1/FVC$) by age and flight hours of high-performance jet pilots. B) Scatter plot of pulmonary function ($FEV_1/FVC$) by age and flight hours of fixed-wing pilots. C) Scatter plot of pulmonary function ($FEV_1/FVC$) by age and flight hours of rotary pilots. D) Scatter plot of pulmonary function ($FEV_1/FVC$) by age and flight hours from the three groups combined.

physiology can adapt, or recover, sufficiently to these harsh environments. While we cannot completely rule out the "healthy worker effect", i.e., only the healthy pilots continue flying, or "survivor-bias" (albeit due to self-selection or switching to a career in leadership), the very low number of pilots being disqualified based on pulmonary problems makes this very unlikely.[18]

The study's strengths include its large sample size and comprehensive dataset covering multiple aircraft categories. To our knowledge, it is the first to investigate the relationship between cumulative flight hours and lung function in active-duty military pilots. The use of a Generalized Estimating Equation model enables robust handling of repeated measurements across time.

Nonetheless, several limitations should be acknowledged. The data cover only pilots' active service, leaving potential postretirement pulmonary effects unexplored. The underrepresentation of female pilots limits sex-based analyses, though this reflects the current composition of military aviation. Performance bias may also be present, as repeated exposure to spirometry testing could improve familiarity and, therefore, potentially affect results.

The highly selective and physically fit military cohort limits the generalizability of findings to civilian pilots. Further research should investigate pulmonary outcomes after retirement and explore whether flight-related exposures outside the cockpit (e.g., deployments) contribute to long-term respiratory health.

While our results suggest that cumulative flight hours do not impair pulmonary function, smoking and aging remain critical risk factors. The utility of frequent spirometry assessments may therefore lie more in monitoring high-risk subgroups, such as older or currently smoking pilots. While smoking status was considered a negative factor for pulmonary function, the distinction between smoking cigarettes and cigars, or the more recently developed e-cigarettes, was not made in our dataset This could be subject for future studies, and these findings may inform revisions to the frequency or targeting of pulmonary screening protocols in military aviation.

This study investigated the relationship between cumulative flight exposure and pulmonary function in military pilots. The findings show that flight hours do not negatively affect the $FEV_1/FVC$ ratio. In contrast, age and current smoking status were significant predictors of pulmonary decline. Pulmonary abnormalities rarely resulted in disqualification from flight duties, suggesting that the burden of disease is low in this population. Given the absence of a negative effect from cumulative flight hours, the necessity of frequent routine spirometry assessments in all pilots may warrant reconsideration. A more targeted screening strategy, perhaps focused on older pilots and those who smoke, may be a more efficient use of resources, provided flight safety is not compromised.

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