High-Performance Aircraft Respiratory Symptom Study

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I have no financial relationships to disclose.

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High-Performance Aircraft Respiratory Symptom (HPARS) Study

• Background and Results Overview
  • Distinct Cough Presentation Clustering
  • Specific Variables of Interest
  • Multivariable Modelling
  • Conclusions
Background

- Study requested by ACC/SG
- Conducted Aug-Oct 2014
  - 5 squadrons at 4 bases in continental United States
    - F-15E training squadron (F-15)
    - F-16 operational squadron (F-16)
    - F-22 operational squadron (F-22O)
    - F-22 training squadron (F-22T)
    - T-38 operational squadron (T-38)
  - 1 month per squadron in 2 increments

- Three study components
  - Retrospective questionnaire (one time, ~7 pages)
  - Prospective questionnaire (after each sortie, 2 pages, checkboxes)
  - Environmental sampling (pre- and post-sortie breath samples, cockpit ozone)

Primary goal: Establish flight-related respiratory symptom “norms” for high-performance aircraft pilots
Secondary goals: Characterize effects of system changes to F-22 & determine etiology of symptoms (if possible)
Results: Overview

- Number of sorties for each type of sortie:
  - F-15
  - F-16
  - T-38
  - F-22 O
  - F-22 T

- Percent of sorties:
  - Cough: 33
  - Shortness: 14
  - Tightness: 32
  - EarBlock: 31
  - Other: 11
  - None: 28

- Other symptoms:
  - 18
  - 7
  - 21
  - 3
  - 1
  - 1
  - 1
  - 1
  - 468
  - 194
  - 118
  - 170

- Value above bar is number of sorties.
Symptom Characterization: Cough

- Distinct presentation of cough in F-22 (All) vs. other airframes
  - F-22 (All) cough is more severe, persistent, and reported on landing
    - 30+ minutes duration, 3/4 reported some discomfort
    - Predominantly present in F-22O
  - Non-F-22 Cough is less uncomfortable, shorter in duration, and begins in-flight
    - <5 minutes in duration, 2/3 report no discomfort
- Oxygen settings not significantly associated with reports of cough in F-22 (All)
- Time spent at high Gz negatively associated with cough in F-22 (All)
  - Despite higher Gz exposure in the F-22 (All) population, within the F-22 (All) population, cough was very rarely reported in high Gz exposure sorties
- Altitude associated with cough in F-22 (All)
Symptom Characterization: Shortness of Breath, Chest Tightness, Ear Block

- **Shortness of breath (SOB) & Chest Tightness**
  - Occurs predominantly after sortie
  - Exception: During sortie for most F-22O
  - Individual susceptibility very important
  - Relatively long-lasting (30+ minutes)
  - SOB & Chest Tightness linked
    - Most reports of SOB were accompanied by reports of chest tightness
    - SOB with chest tightness: more likely to have prolonged SOB (statistically significant)

- **Ear Block**
  - Predominantly F-22O
  - Individual susceptibility not as notable as for other symptoms
  - Virtually all ear block still occurring during questionnaire for F-15E and F-22O

- “Other” symptoms largely benign
HPARS Initial Analysis Takeaways

13%
- 13% of sorties had an associated respiratory symptom
- Most common: cough and chest tightness

1/3
- Individual susceptibility important
- 31.5% of pilots ever reported symptoms

3
- Three distinct groupings:
  - F-22O
  - F-15 & F-16
  - F-22T & T-38

F-22 & time
- F-22 symptoms improved compared to previous studies

??
- Symptom etiology not clear

Mayes – HPARS, ICASM 2017
High-Performance Aircraft Respiratory Symptom (HPARS) Study

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- **Distinct Cough Presentation Clustering**
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- Multivariable Modelling
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F-22 cough is more likely to occur after sortie than other airframes
- 14% of F-22O sorties report cough with onset after sortie against only 2% outside F-22O

F-22 cough is less likely to begin during sortie
- 1.1% of F-22 (All) sorties report cough with onset during sortie against 3.2% outside F-22 (All)

Both comparisons are statistically significant
Previous findings noted relationship between cough and chest tightness

- 69% of after sortie onset cough reported “a little discomfort” or more; 26% of during sortie onset cough reported “a little discomfort” or more\(^1\)
- 54% of after sortie onset cough reported co-occurrence of tightness of chest on same sortie; 14% of during sortie onset cough reported co-occurrence of tightness of chest on same sortie\(^2\)
- Both associations are statistically significant
Distinct Presentations by Time of Onset

F-22 cough distinct from cough in other airframes on a variety of measures

The unique operating environment of the F-22 may explain distinction

- Difference in operations and in cough rates at the F-22 operational vs. training squadrons sampled
Airframe Exposures vs. Total Cough by Airframe

- F-22O operational use distinctly different than other airframes
- All F-22 had higher altitude operations in this study
- Difficult to distinguish operational from airframe associations
- Only in F-22O was there a strong association between cough and chest tightness reports
  - F-15 and F-16 reported weak associations
  - F-22T and T-38 had insufficient cough/tightness for meaningful analysis
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Oxygen Setting and Cough

- Oxygen setting analysis based upon self-report of setting in F-22 (All)
- No significant association between O2 setting and cough was found
- Not a controlled experiment, treat results with caution
  - Individual variability important
  - Self-selected population may explain reduced cough

Proportion of Sorties with Reported Cough

<table>
<thead>
<tr>
<th>Reported Oxygen Setting</th>
<th>Max</th>
<th>Auto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion</td>
<td>2%</td>
<td>32%</td>
</tr>
</tbody>
</table>

Reported Oxygen Setting

Not Significant
As 7+ Gz exposure increases\(^1\), cough rate decreases
- Most significant drop from <1 second to >1 second\(^2\)

17/23 instances of cough occurred in sorties with <1 second at 7+ Gz
No association based on when Gz occurred during sortie
F-22 Flight Data: Mean Altitude vs. Cough

- F-22 Cough related to mean altitude during sortie
  - Above 16k mean altitude, 12.0% cough (n = 166)\(^1\)
  - Below 16k, 2.6% (n=117)\(^2\)

- 20/23 instances of cough occurred in sorties with >16k mean altitude

\(^1\) \(^2\)
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Multivariable Model Methods

Generalized Linear Model
- Included maximum altitude, presence of cough on prior sortie, difference between mean and maximum altitude, and subjective heavy G-time
- Limited to pilots who reported cough on at least one sortie
- R-squared of 0.52

Partition Model
- Simple discriminant-based classification system
- Based on high mean altitude, low 7+ Gz exposure risk profile
- Identifies high-risk exposures
- Extension of partition model into other airframes was not predictive
- Partition model was not predictive for non-cough symptoms
F-22 Partition Model

Partition model effective at classifying F-22 cough
- 83% of F-22 cough sorties as high risk (19/23)
- 70% of non-cough sorties as low risk (183/260)

High (>20k ft) low Gz (<2 seconds over 7+ Gz) F-22 sorties are 11.2x as likely to report cough
- 2.1% of sorties classified low risk reported cough
- 20.0% of sorties classified high risk reported cough

Area under ROC:
- 0.73 for altitude
- 0.78 for Gz

Partition model not predictive for other airframes

High Altitude and Low Gz Sorties Experienced >10x Cough
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Conclusions

Two distinct types of cough – during sortie onset and after sortie onset

- During sortie onset cough not easily predicted / characterized

After sortie cough relatively well-characterized

- Often associated with other symptoms (chest tightness, SOB)
- After-sortie cough more likely to report discomfort
- After-sortie cough longer in duration than during-sortie cough (previous results)
- Clustered in F-22O
- Associated with features of flight; sorties with after-sortie cough more likely to be high altitude without high Gz
- Altitude predictive of cough, but oxygen setting not associated with cough
Conclusions

- After sortie cough *not* consistent with classic acceleration atelectasis
- Prolonged shortness of breath post-sortie associated with reports of chest tightness
- Cannot easily distinguish airframe-specific differences from operational exposures
  - F-22O vs. F-22T differences suggest operational exposures (flight regime) may be more important than airframe
Questions?

Special Thanks to: Mr. Ben Clapp & Mr. Chuck Goodyear

Contact: Ryan.Mayes.2@us.af.mil
Extended Multivariable Models

Partition model demonstrates specificity and accuracy at a range of discrimination thresholds.
Future Work

- **Multifactorial Modelling**
  - Further development of Simulation to Predict Impact of Multiple Factors on Respiratory Function

- **Investigate Gz-Cough Association**
  - Identify potential mechanisms for Gz to prevent/mitigate cough through deep dive in F-22 Integrity data and literature

- **Exhaled Breath & Ozone Data**
  - Analysis to be repeated with different software; IPA may be significant in cough analysis
  - Validate identity of chemicals
  - Bigger Challenge: identify source(s), delivery, and mitigations for chemicals identified in study (in-line sensing)

- **Future studies**
  - Further study on aircrew physiology using mask sensors
    - Follow-on study for symptom incidence?
  - 4 approved air quality studies
    - Legacy jet air sampling
    - Quantification, exposure reconstruction, tox assessment for significant peaks
    - Assess IPA uses and concentrations in MX activities
    - IPA specific sensor to be built
Discussion: Indexed Relative Variance

Separated presentations into distinct populations suggests distinct etiology

Different environment in F-22 (All)
- F-22 flew higher and generally faster, especially F-22O
- Cough occurs higher and generally faster in combined populations
- Within F-22 (All), cough occurs higher and slower
Previous Results Overview

- 13% of high-performance aircraft sorties associated with one or more respiratory symptoms
  - Most common symptoms: cough and chest tightness
- F-22 symptoms improved compared to previous studies
  - Operational F-22 pilots report more symptoms than other high-performance aircraft pilots
- Symptom etiology unclear: likely multifactorial
  - Cough not consistent with classic acceleration atelectasis
  - Cough and chest tightness related

### Graph

- **Percent of Sorties**
- **Value above bar is number of sorties**

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Cough</th>
<th>Shortness</th>
<th>Tightness</th>
<th>EarBlock</th>
<th>Other</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-15</td>
<td>33</td>
<td>14</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>F-16</td>
<td>32</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>T-38</td>
<td>28</td>
<td>54</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>F-22 O</td>
<td>118</td>
<td>468</td>
<td>194</td>
<td>160</td>
<td>170</td>
<td></td>
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<td>15</td>
<td>3</td>
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Cough: 33, Shortness: 32, Tightness: 54, EarBlock: 468, Other: 160, None: 170
Symptom Characterization: F-22O Cough

- **F-22O**: highest cough rate of any squadron sampled (included F-15E, F-16, and T-38)
  - No difference in cough by sustained Gz; sorties with higher maximum Gz less likely to have cough
  - Sorties with UPG more likely to result in cough (note: sorties were all high-altitude) – statistically higher than sorties without UPG
  - Sorties with OBOGS MAX resulted in cough half as often than sorties with OBOGS Auto
  - Sorties with mean altitude >27k not statistically different for cough than sorties with mean altitude ≤27k
    - Caveat: some association with max altitude above vs. below 27k; higher max altitudes associated with more cough (only 21 sorties with max<27k)
  - For F-22, cough typically begins after sortie, lasts 30+ minutes, and has some level of discomfort

- **F-22 cough not consistent with classic acceleration atelectasis (high O₂ + Gz)**
  - Symptoms predominantly began after flight
  - Symptoms typically last 30+ minutes

- **Cough at other squadrons more consistent with acceleration atelectasis**
  - Began during sortie, lasted <2 minutes
  - Less discomfort than F-22 cough
Ozone

- Cockpit ozone results largely unremarkable; readings were below levels associated with respiratory symptoms
- Highest ozone measurements were found with long-duration sorties (>2.8 hours)
- Planned work will investigate whether there is any relationship between ozone and symptoms; null findings expected
Individual Susceptibility

- Individual susceptibility a significant factor: single best predictor of major symptoms is whether pilot reported symptoms in past
  - 4 pilots account for 25% of all reported symptoms
  - However, most pilots reporting symptoms only did so occasionally (<100% of sorties)
  - Most pilots (68.5%) did not report any symptoms
- Symptoms not randomly distributed across individuals; rates partially driven by susceptible individuals
Symptom Characterization: Cough

- Cough for F-22O is predominantly after sortie and more frequent than other bases
  - F-15E predominantly during sortie
  - F-16 about even
- Individual susceptibility important
  - F-22O: 3 pilots reported 20/32 instances of cough
  - F-15E: 3 pilots reported 15/33 instances of cough
- Cough during sortie
  - Mostly short in duration (1-5 minutes)
  - 67% of those reporting cough during sortie reported no discomfort
  - However, some cough lasted through time of survey (30-60+ minutes)
    - 8/23 for F-15E
    - 5/6 for F-16
    - 0/4 for F-22O (1 unspecified)
  - Unusual observation for F-15E: more cough with PBG than with regulator set to "on" (no PBG)
- Cough after sortie
  - Long in duration: 30+ minutes (still occurring at time of survey)
  - 25% reported no discomfort (75% reported little or some discomfort)
    - 26/40 for F-22O were 30+ minutes
    - However, only 2/10 for F-15E were 30+ minutes (7/10 were ≤ 10 minutes)
Of those who experienced prolonged Shortness of Breath (SOB), the majority also had comorbid chest tightness. Most reports of SOB were accompanied by reports of chest tightness. SOB with chest tightness: more likely to have prolonged SOB – Statistically significant.