Operational Epidemiology: An Outbreak Investigation Approach to F-22 Physiologic Incidents

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F-22 Background

- **U.S. Air Force-exclusive 5th-generation fighter**
- **Multiple unexplained physiologic incidents among F-22 pilots 2008-2012**
  - **Fleet-wide standdown May-Sept 2011**
  - **Incidents continued to occur after return-to-fly (21 Sept 2011)**
- **Multi-year investigation into cause of incidents, great deal of public attention**
  - **Several investigatory bodies involving multiple government agencies as well as industry**
- **F-22 Task Force concluded that aircrew flight equipment (AFE) was a major cause of F-22 physiological incidents**

Traditional Outbreak Investigation Steps*

1. **Field work preparation**
2. **Establish outbreak existence**
3. **Confirm diagnosis**
4. **Define and identify cases**
5. **Describe and orient the data in terms of time, place, and person**
6. **Develop hypotheses**
7. **Evaluate hypotheses**
8. **Refine hypotheses and carry out additional studies**
9. **Implement control and prevention measures**
10. **Communicate findings**
11. **(Maintain surveillance)**
    - **Not included in CDC steps, but often implemented in practice**

*CDC: http://www.cdc.gov/excite/classroom/outbreak/steps.htm

Operational Outbreak Investigation: Step 1

TRADITIONAL OUTBREAK STEP: (1) FIELD WORK PREPARATION

F-22 Investigation Application:

- Background research
  - Design/role of F-22
  - Known information on unexplained incidents
- Identify/assemble team
  - Flight surgeon, physiologist, engineer, statistician, epidemiologist, database programmer, physicist, research psychologist, life support expert, etc.
- Identify involved parties & establish communication lines F-22 stakeholders
  - Investigatory bodies (SAB, Task Force, SIBs)
- Determine role in investigation
  - 711th HPW role expanded over time

SAB: Scientific Advisory Board Aircraft Oxygen Generation Quicklook Study
Task Force: F-22 Life Support Systems Task Force
SIB: Safety Investigation Board

Lessons Learned:

- Assemble team more quickly
  - Perhaps pre-formed team "on call"
- More analytic capability
  - Enables multiple other steps (establish existence of outbreak, evaluate hypotheses, etc.)
  - Difficult to spin up on short notice
- Better defined roles & responsibilities

Proposed "Operational Outbreak" Step:

(1) Investigation preparation

- **Not limited to field work**

Operational Outbreak Investigation: Step 2

TRADITIONAL OUTBREAK STEPS: ~~(3) CONFIRM DIAGNOSIS~~ AND (4) DEFINE AND IDENTIFY CASES

F-22 Investigation Application:

- Not possible to confirm diagnosis
  - Unknown cause, undefined outcome
- Formal “case definition” may not be possible
- Identify presumptive cases
- Group cases if possible (will drive hypothesis development)
- Create (working) inclusion/exclusion criteria based on common features, adjust criteria as needed throughout process
  - Example: physiologic symptoms, reduced ability to fly, no known cause BUT exclude if clear mechanical cause
  - Number of cases changed as inclusion/ exclusion criteria and understanding of incidents matured

Lessons Learned:

- This step must be flexible, will be iterative
- Vital to establish a place to start
- Ensure all investigatory bodies aware of inclusion/exclusion criteria

Proposed “Operational Outbreak” Step:

(2) Identify cases, create (dynamic) inclusion & exclusion criteria

Operational Outbreak Investigation: Step 3

TRADITIONAL OUTBREAK STEP: (2) ETABLISH OUTBREAK EXISTENCE

F-22 Investigation Application:

- Compare F-22 hypoxia-like incident rate to other tactical aircraft
  - Per SAB, F-22 rate was higher than “endemic” (F-15E, F-16, etc.)
  - Studies conducted by 711 HPW confirmed higher unknown-cause incident rate
- Denominator data critical
- Comparison establishes need for further investigation

Lessons Learned:

- Must identify cases first (have inclusion/exclusion criteria, etc.)
  - F-22 “case definition” a moving target initially, created challenges when communicating to leadership

Proposed “Operational Outbreak” Step:

(3) Establish the existence of an outbreak

Operational Outbreak Investigation: Step 4

TRADITIONAL OUTBREAK STEP: (5) DESCRIBE/ORIENT THE DATA

F-22 Investigation Application:

- Traditional outbreak approach not highly relevant for unknown outcomes, hypothesis generation should proceed description of data
- Data collection critical, however
- Gather existing data in central and accessible location
  - 711 HPW became F-22 data repository
  - Established connections with other F-22 data centers
- Identify gaps in knowledge
  - Breathing air quality
  - Breathing air quantity
  - Pilot physiologic outcomes

Lessons Learned:

- Centralized data collection, processing, and analysis vital to investigation
  - Simplifies identification of gaps

Proposed "Operational Outbreak" Step:

(4) Gather existing data, identify gaps

Operational Outbreak Investigation: Step 5

TRADITIONAL OUTBREAK STEP: (6) DEVELOP HYPOTHESES

F-22 Investigation Application:

- Develop and prioritize hypotheses
  - Prioritization important given size of investigation
  - More resources initially dedicated to "most likely" theories
  - Prioritization enables reevaluation of hypotheses (step 7)
- Establish investigatory structure; how will each hypothesis be approached and who will investigate each?
  - Necessary for very large investigation; hundreds of hypotheses examined
- Consult experts from all pertinent fields
  - Multiple hypothesis types (engineering factors, human factors, man-machine interface)
  - Experts from each field needed
  - Cooperation between Department of Defense and industry critical

Lessons Learned:

- Community engagement at this stage would be invaluable
  - Didn't consult operators until later in process

Proposed "Operational Outbreak" Step:

(5) Develop and prioritize hypotheses

Operational Outbreak Investigation: Step 6

TRADITIONAL OUTBREAK STEP: (7) EVALUATE HYPOTHESES

F-22 Investigation Application:

- Evaluation (analytic epidemiology)
  - Small numbers problem
    - Solved through simulation, imputation
  - Paired comparisons to evaluate data without known standards
    - Incident pilot vs. wingman
  - Integrity data major challenge
    - Cohort-type approach
    - Topographical analysis
  - Operational data
    - Pulse oximetry, C2A1 analysis, etc.
  - Formal experiments (centrifuge, etc.)
- Tracking
  - Root Cause Corrective Analysis (RCCA) used
  - Useful for grouping hypotheses, consolidating efforts, etc.

Lessons Learned:

- RCCA useful but has limitations
  - Not ideal for physiology or multiple factors

Proposed "Operational Outbreak" Step:

(6) Track and evaluate hypotheses

- Evaluate with empirical data

Operational Outbreak Investigation: Step 7

TRADITIONAL OUTBREAK STEP: (8) REFINE HYPOTHESES & CARRY OUT STUDIES

F-22 Investigation Application:

- Apply findings to previous hypotheses, identify remaining gaps
  - No evidence to support that incidents were caused by contaminants
  - No evidence to support that symptoms were due to classic hypoxia
  - Many initial hypotheses ruled out
- Communicate with all stakeholders (include operators/end-users)
  - Pilot input led to additional hypotheses (work of breathing)
- Conduct further studies
  - Altitude chamber
  - Centrifuge
  - Flight testing

Lessons Learned:

- Community input received at this stage proved invaluable
  - Should have engaged with pilots much earlier (when initially developing hypotheses)

Proposed "Operational Outbreak" Step:

(7) Refine hypotheses & carry out additional studies

Operational Outbreak Investigation: Step 8

TRADITIONAL OUTBREAK STEP: (9) IMPLEMENT CONTROL AND PREVENTION MEASURES

F-22 Investigation Application:

- Implement changes when evidence supports
  - Remove C2A1 filter
  - Improve AFE fitting procedures
  - Redesign upper pressure garment (UPG) fill/dump valve
- Track changes over time
  - Allows assessment of impact of those changes
  - C2A1 filter initially installed as mitigation, but may have contributed to incidents

Lessons Learned:

- Communicate control and prevention measures taken

Proposed "Operational Outbreak" Step:

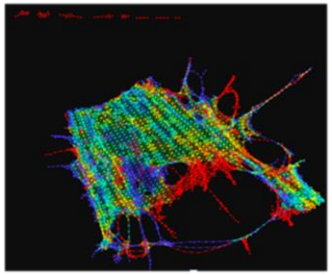
(8) Implement control and prevention measures

Operational Outbreak Investigation: Step 9

TRADITIONAL OUTBREAK STEP: (10) COMMUNICATE FINDINGS

F-22 Investigation Application:

- Communicate findings:
  - Vitally important, not just to leadership but communicate to operators as well
  - Consistent feedback loop
- Provide inputs for research:
  - Multiple knowledge gaps revealed during investigation
  - Used to direct relevant research
  - F-22 investigation informs research at 711 HPW



Lessons Learned:

- Operators not always informed of progress while investigation underway
- Ongoing communications to F-22 pilots would have been advantageous

Proposed "Operational Outbreak" Step:

(9) Communicate findings and provide inputs for further research

Operational Outbreak Investigation: Step 10

TRADITIONAL OUTBREAK STEP: (11) MAINTAIN SURVEILLANCE

F-22 Investigation Application:

- Confirm control measures or other actions have effectively contained outbreak
  - No unexplained physiologic incidents since UPG removed
  - No incidents since C2A1 canisters removed

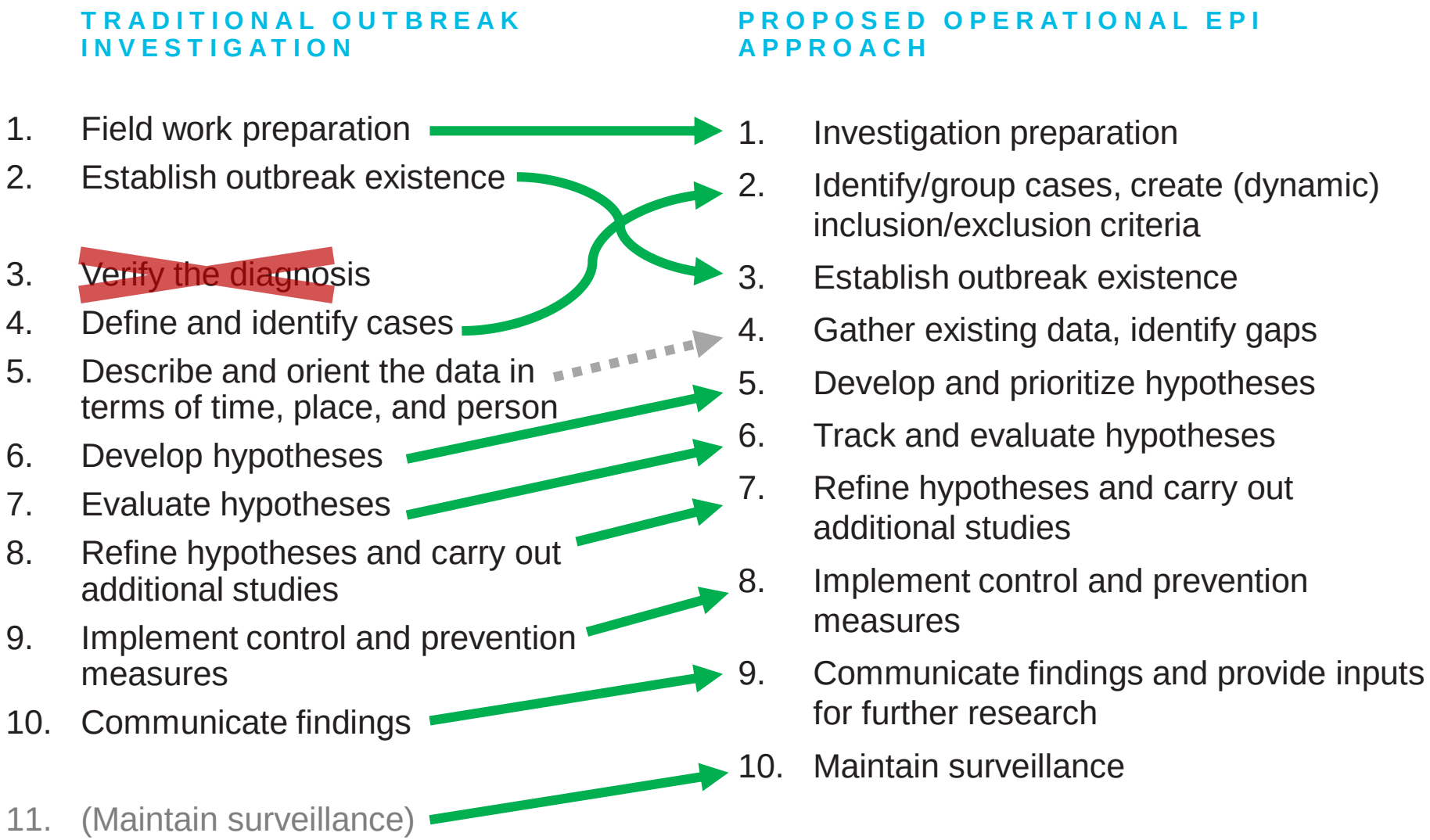
Lessons Learned:

- Continued surveillance helps to further evaluate hypotheses
  - Also helps bolster findings when communicating results to stakeholders and/or decision makers

Proposed "Operational Outbreak" Step:

(10) Maintain surveillance

Outbreak Investigation Step Comparison



Operational Epidemiology: Outbreak Investigation Steps

1. **Investigation preparation**
2. **Identify/group cases, create (dynamic) inclusion/exclusion criteria**
3. **Establish outbreak existence**
4. **Gather existing data, identify gaps**
5. **Develop and prioritize hypotheses**
6. **Track and evaluate hypotheses**
7. **Refine hypotheses, carry out additional studies**
8. **Implement control/prevention measures**
9. **Communicate findings & provide inputs for further research**
10. **Maintain surveillance**

Questions?

The views expressed are those of the author and do not necessarily represent the official position or policy of the Air Force, the Department of Defense, or the U.S. Government.

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