CREW WORKLOAD STRATEGIES
IN ADVANCED COCKPITS

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NASA Ames Research Center
ABSTRACT

Many methods of measuring and predicting operator workload have been developed that provide useful information in the design, evaluation, and operation of complex systems and which aid in developing models of human attention and performance. However, the relationships between such measures, imposed task demands, and measures of performance remain complex and even contradictory. It appears that we have ignored an important factor: people do not passively translate task demands into performance. Rather, they actively manage their time, resources, and effort to achieve an acceptable level of performance while maintaining a comfortable level of workload. While such adaptive, creative, and strategic behaviors are the primary reason that human operators remain an essential component of all advanced man-machine systems, they also result in individual differences in the way people respond to the same task demands and inconsistent relationships among measures. Finally, we are able to measure workload and performance, but interpreting such measures remains difficult; it is still not clear how much workload is "too much" or "too little" nor the consequences of suboptimal workload on system performance and the mental, physical, and emotional well-being of the human operators. The rationale and philosophy of a program of research developed to address these issues will be reviewed and contrasted to traditional methods of defining, measuring, and predicting human operator workload.
PREVIOUS RESEARCH GOALS
TO EXPLAIN, QUANTIFY, AND PREDICT RELATIONSHIPS AMONG:

OBJECTIVE TASK DEMANDS

EXPERIENCED WORKLOAD ↔ SYSTEM PERFORMANCE

LESSONS LEARNED

OBJECTIVE TASK DEMANDS

- MEASURES ARE RELATIVE
- HIGH VARIABILITY
- NO "REDLINES"
- TOO MANY MEASURES
- NO FIGURES OF MERIT
- NO STANDARDIZATION
- INCONSISTENT RELATIONSHIPS

EXPERIENCED WORKLOAD ↔ SYSTEM PERFORMANCE
EFFECTIVENESS OF COMPUTER-GAME TRAINER IN IMPROVING WORKLOAD MANAGEMENT SKILLS

FLIGHT 7: LEAVING PRACTICE AREA

CONTROL GROUP BETTER  GAME GROUP BETTER

FLIGHT 7 PREDICTOR SCORES

PREDICTOR SCORES AFTER FLIGHT 8

GAME TRAINING GROUP

EFFECTIVENESS OF AUTOMATION IN RELEASING RESOURCES TO PERFORM OTHER TASKS

PERCENT TIME OUT OF FLIGHT ENVELOPE

PERCENT OF TARGET "KILLS".

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ELEMENT 4: METHODS OF IMPROVING STRATEGIES

MILESTONES:

IDENTIFY OPTIMAL STRATEGIES FOR TYPICAL FLIGHT TASKS AND SITUATIONS

DEVELOP TRAINING PROCEDURES TO IMPROVE PILOTS' MANAGEMENT OF TIME, RESOURCES, STRATEGY SHIFTS APPROPRIATE FOR STATE

DEVELOP CONCEPTUAL DESIGNS FOR COMPUTER AIDS TO IMPROVE PILOTS' ABILITIES TO SELECT APPROPRIATE PLANS, STRATEGIES AND TACTICS

TEST CONCEPTUAL DESIGNS FOR INFIGHT ADAPTIVE SYSTEMS FOR DYNAMIC TASK ALLOCATION

INDIVIDUAL DIFFERENCES IN SUBJECTIVE WORKLOAD "REDLINES"

[Graphs and charts depicting subjective workload for different subjects]
BOREDOM: PERFORMANCE/PHYSIOLOGICAL CORRELATES

PHYSIOLOGICAL MEASURES

AVERAGED DATA FROM 11 SUBJECTS SHOWS CORRELATION OF 3 PHYSIOLOGICAL MEASURES

HEART RATE VARIABILITY VS BLOCK NUMBER
HEART RATE VARIABILITY VS ALPHA VARIANCE
HEART RATE VARIABILITY VS PUPIL DIAMETER

EFFECT OF BOREDOM ON PERFORMANCE, WORKLOAD

INFLUENCE OF BOREDOM ON RATED WORKLOAD

INFLUENCE OF BOREDOM ON PERFORMANCE

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## SYMPTOMS OF UNDER/OVERLOAD STATES

<table>
<thead>
<tr>
<th>Workload</th>
<th>Subjective Experience:</th>
<th>Physiological Indices:</th>
<th>Strategies:</th>
<th>Performance:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unacceptable (Too High)</td>
<td>Overwhelmed</td>
<td>Significant Change</td>
<td>None</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Suboptimal</td>
<td>Stressed</td>
<td>Some Change</td>
<td>Compensation: - Shed - Defer</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Optimal</td>
<td>Comfortable</td>
<td>&quot;Normal&quot;</td>
<td>Manage Task Demands</td>
<td>Good</td>
</tr>
<tr>
<td>Suboptimal</td>
<td>Bored</td>
<td>Some Change</td>
<td>Compensation: Tries to Maintain Arousal</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Unacceptable (Too Low)</td>
<td>Drowsy</td>
<td>Significant Change</td>
<td>Unprepared</td>
<td>Poor</td>
</tr>
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### ELEMENT 3: WORKLOAD "RED-LINES"

<table>
<thead>
<tr>
<th>Milestones</th>
<th>FY89</th>
<th>FY90</th>
<th>FY91</th>
<th>FY92</th>
<th>FY93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify variables associated with under/overload</td>
<td></td>
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<tr>
<td>Identify performance/physiological correlates of subjective over/underload states</td>
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<tr>
<td>Investigate role of individual differences in personal workload criteria</td>
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<tr>
<td>Quantify impact of strategies in dynamic workload/performance tradeoffs</td>
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<tr>
<td>Model workload/performance tradeoffs</td>
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<tr>
<td>Quantify over/underload regions for workload measures</td>
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<tr>
<td>Develop standard procedures for aircraft certification</td>
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</tbody>
</table>
SCHEDULING THEORY MODELS OF WORKLOAD

INFLUENCE OF STRATEGY ON RATED WORKLOAD

TIME AVAILABLE:

- 20% MORE THAN NEEDED
- JUST ENOUGH
- 20% LESS THAN NEEDED

RATING

0 1 2 3 4 5 6

SHORTEST TIME OPTIMAL STRATEGY

TEMPORAL DYNAMICS OF MENTAL WORKLOAD

TARGET SEQUENCE

MENTAL WORKLOAD

PERCEIVED DISTANCE FROM GOAL

EFFECTIVE TIME FOR ACTION

STABLE LOAD LEVEL

INSTABLE LOAD LEVEL

EFFICIENT TIME
SHAPA: VERBAL/NONVERBAL PROTOCOL ANALYSIS TOOL

FEATURES:
- RUNS ON IBM-AT WITH EGA
- FULLY INTERACTIVE
- ENCODER DETERMINES ENCODING MODEL/THEORY
- FASTER ENCODING
- CHOICE OF DATA ANALYSIS TECHNIQUES
- DIRECT ENGAGEMENT WITH DATA

UNDER DEVELOPMENT: MacSHAPA
- MULTIPLE INTERACTING AGENTS
- MULTIPLE STREAMS OF VERBAL AND NON-VERBAL BEHAVIORS
- MULTIPLE ENCODERS/RESEARCHERS
- VISUALIZATION TOOLS

MODEL FOR CODING VERBAL PROTOCOLS TO ASSESS PILOT STRATEGIES
WORKLOAD /PERFORMANCE FOR COMPONENT TASKS

WINDOWS DISPLAY

TRACKING ERROR FOR CONTROL TASK

RATED WORKLOAD OF TASK COMPONENTS

RESPONSE LATENCY FOR DISCRETE TASKS

REAL-TIME MEASUREMENT OF MENTAL WORKLOAD

PERCENT CORRECTLY CLASSIFIED TRIALS: ERP MEASURES

ARITHMETIC TASK: RESPONSE TIME

GAUGE MONITORING TASK: RESPONSE TIME

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APPLICATION OF EVOKED POTENTIAL MEASURES IN COCKPIT SIMULATOR

SENSITIVITY OF CARDIOVASCULAR MEASURES

<table>
<thead>
<tr>
<th></th>
<th>Flight Path</th>
<th>Control Guidance</th>
<th>Display Format</th>
<th>Time On Task (Underload)</th>
<th>Task Pacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Heart Rate</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart Rate Change</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart Rate Variability</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Blood Pressure Component HRV (0.1Hz)</td>
<td>+</td>
<td>+</td>
<td></td>
<td>++</td>
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</table>

++ NOT USEFUL
SHOWS TRENDS
++ STATISTICALLY SIGNIFICANT
INFLUENCE OF DISPLAY DESIGN ON PILOT’S HEART RATE

STEREO vs NON-STEROE LNDG/APPR DISPLAY
HEART RATE INCREASE (BASELINE TO TD)

COMPARISON AMONG MEASURES
INFERENCES ABOUT "EFFORT" AND WORKLOAD CANNOT BE DRAWN FROM MEASURES OF REACTION TIME

EXAMPLE 1:

RESPONSE TIME

WORKLOAD

EXAMPLE 2:

RESPONSE TIME

WORKLOAD

HYPOTHETICAL RELATIONSHIPS BETWEEN TASK DEMANDS, EFFORT, MEASURES OF PERFORMANCE, AND WORKLOAD
PILOTS ADOPT DIFFERENT STRATEGIES WITHIN A FLIGHT

<table>
<thead>
<tr>
<th>UNDERLOAD</th>
<th>LEAD</th>
<th>LAG</th>
<th>OVERLOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERFORM TASKS UNRELATED TO MISSION</td>
<td>PERFORM MISSION TASKS AHEAD OF SCHEDULE</td>
<td>PLAN SITUATION AWARENESS, REHEARSE</td>
<td>REACT</td>
</tr>
<tr>
<td>DEFER TASKS, RELAX PERFORMANCE CRITERIA</td>
<td>SHED TASKS, OFF-LOAD</td>
<td></td>
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</tbody>
</table>

PILOT WORKLOAD:
- TOO LOW
- LOW
- MODERATELY HIGH
- TOO HIGH

HYPOTHETICAL DISTRIBUTIONS OF STRATEGIES

CHARACTERISTICS OF STRATEGIC BEHAVIORS

DEVELOPMENT/SETTING OF HIGH LEVEL GOALS (OPEN-LOOP)

DYNAMIC SELECTION AMONG ALTERNATIVE SEQUENCES OF ACTIONS TO ACHIEVE A GOAL

CLOSED-LOOP, RELATIVELY AUTOMATIC, PERFORMANCE OF ACTIONS APPROPRIATE FOR SELECTED STRATEGY
ELEMENT 2: STRATEGIC BEHAVIOR

<table>
<thead>
<tr>
<th>MILESTONES:</th>
<th>FY89</th>
<th>FY90</th>
<th>FY91</th>
<th>FY92</th>
<th>FY93</th>
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</thead>
<tbody>
<tr>
<td>DEVELOP COMMON RESEARCH ENVIRONMENT FOR PROGRAM PARTICIPANTS</td>
<td></td>
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<tr>
<td>ADOPT STANDARD METHOD OF IDENTIFYING STRATEGIES</td>
<td></td>
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<tr>
<td>QUANTIFY PERFORMANCE/WORKLOAD CORRELATES OF SPECIFIC STRATEGIES/STRATEGY SHIFTS</td>
<td></td>
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<tr>
<td>INVESTIGATE ROLE OF PILOT STATE AND INDIVIDUAL DIFFERENCES ON STRATEGIC BEHAVIOR</td>
<td></td>
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<tr>
<td>CLASSIFY STRATEGIES TYPICAL OF VARIOUS TASKS, ENVIRONMENTS</td>
<td></td>
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<tr>
<td>DETERMINE WHY PILOTS ADOPT OR ABANDON PLANS AND STRATEGIES</td>
<td></td>
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</tr>
<tr>
<td>QUANTIFY RELATIONSHIP BETWEEN STRATEGIES, WORKLOAD, AND PERFORMANCE IN FLIGHT</td>
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</table>

FIGURES OF MERIT - II

GOAL:
IDENTIFY A PARSIMONIOUS SET OF VARIABLES WHICH, IN COMBINATION, ARE DESCRIPTIVE OF THE INFLUENCE OF THE PILOT/VEHICLE INTERFACE DESIGN AND PILOT'S INTENT ON SYSTEM PERFORMANCE

APPROACH:
- SELECT 50 VARIABLES FROM THOSE ALREADY AVAILABLE
- MONITOR PERFORMANCE OF NOVICE AND EXPERT PILOTS IN AFTI F-16 DURING:
  - AIR-TO-AIR MISSION
  - TERRAIN-FOLLOWING MISSION
- MEASURE PILOT WORKLOAD USING SWAT
- SELECT PARSIMONIOUS SET OF VARIABLES USING MULTI-DIMENSIONAL SCALING, CLUSTER ANALYSIS, ETC
  - IDENTIFY REDUNDANT MEASURES
  - IDENTIFY MEASURES THAT PROVIDE UNIQUE INFORMATION
  - COMBINE SOME MEASURES TO CHARACTERIZE A PARTICULAR ASPECT OF PERFORMANCE
FIGURES OF MERIT - I

GOAL:
DEVELOP COMPOSITE FIGURE OF MERIT FOR PERFORMANCE

APPROACH:
• EXPERIMENTAL TASK (SCORE):
  — 10-MIN TRIALS
  — 2nd-ORDER, 1-AXIS PURSUIT TRACKING
  — MONITOR 8 DIALS
  — ONLINE SUBTASK PERFORMANCE FEEDBACK
• FIGURE OF MERIT
  — EQUALLY WEIGHTED AVERAGE OF:
    • TRACKING (% MAX ERROR; 1-10)
    • MONITORING (% MAX ERROR; 1-10)
    • SELF EVALUATION (ONCE PER MIN)

RESULTS:
• Ss FOCUSED ON TRACKING (BASED ON PERFORMANCE STRATEGY, SELF RATING)
• EQUAL WEIGHTING INAPPROPRIATE

FIGURES OF MERIT ARE NEEDED THAT CAPTURE THE QUALITY OF OVERALL PERFORMANCE

DISCRETE TASKS

CONTINUOUS TASKS

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TRADITIONAL MEASURES LOSE THEIR MEANING IF OPERATORS DO NOT TRY TO RESPOND: (1) IMMEDIATELY AND (2) PERFECTLY

DISCRETE TASKS

CONTINUOUS TASKS

TRADITIONAL MEASURES OF PERFORMANCE

DISCRETE TASKS:

CONTINUOUS TASKS:
ELEMENT 1: FIGURES OF MERIT (FoM)

MILESTONES:

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<thead>
<tr>
<th>FY89</th>
<th>FY90</th>
<th>FY91</th>
<th>FY92</th>
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<tbody>
<tr>
<td>SELECT SET OF TARGET TASKS</td>
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<tr>
<td>IDENTIFY APPROPRIATE SUBTASK MEASURES</td>
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<tr>
<td>SPECIFY ACCEPTABLE PERFORMANCE FOR TARGET TASKS</td>
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<tr>
<td>DEVELOP GENERALIZED PROCEDURES FOR CREATING FIGURES OF MERIT</td>
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<tr>
<td>TEST WITH EXISTING DATA BASES</td>
<td></td>
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</tr>
<tr>
<td>USE IN LAB, SIMULATOR, FLIGHT RESEARCH</td>
<td></td>
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<tr>
<td>INTEGRATE INTO &quot;REDLINE&quot; AND STRATEGIC BEHAVIOR ELEMENTS OF PROGRAM</td>
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</tr>
</tbody>
</table>

PROGRAM ORGANIZATION: LEAD ROLES

LEAD CENTER(S):
N.A. NASA AMES
N.A. NASA WALTON
AF. AIR FORCE AMRL

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### PROGRAM ELEMENTS/MAJOR MILESTONES

**GOALS:**
- Establish MOA
- Develop Performance Figures of Merit
- Quantify Effects of Strategic Behavior, Pilot State
- Identify Evaluation Criteria for Workload Measures
- Improve Pilots' Abilities to Manage Workload Extremes

<table>
<thead>
<tr>
<th></th>
<th>FY89</th>
<th>FY90</th>
<th>FY91</th>
<th>FY92</th>
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<tr>
<td>GQAL</td>
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<tr>
<td>ESTABLISH MOA</td>
<td></td>
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<tr>
<td>DEVELOP PERFORMANCE FIGURES OF MERIT</td>
<td></td>
<td></td>
<td>1, 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QUANTIFY EFFECTS OF STRATEGIC BEHAVIOR, PILOT STATE</td>
<td></td>
<td></td>
<td>1, 2, 3, 4</td>
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<tr>
<td>IDENTIFY EVALUATION CRITERIA FOR WORKLOAD MEASURES</td>
<td></td>
<td></td>
<td></td>
<td>1, 2</td>
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<tr>
<td>IMPROVE PILOTS' ABILITIES TO MANAGE WORKLOAD EXTREMES</td>
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<td>4, 5</td>
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</tbody>
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**PRODUCTS:**
1. Predictive Tools for System Designers
2. Standard Evaluation Procedures for Aircraft Certification
3. Improved Theoretical Model of Workload
4. Workload-Management Training Concepts
5. Adaptive Computer Aids to Improve Task Allocation

### PROPOSED EXPLANATION

**Objective Task Demands**

- Pilot State
- Strategies

**Experienced Workload**

**System Performance**
CURRENT CONCEPTUALIZATIONS OF WORKLOAD GENERALLY IGNORE THE DYNAMIC, ADAPTIVE, CREATIVE BEHAVIOR OF HUMAN OPERATORS