DEVELOPMENT OF AN INTELLIGENT AGENT FOR FUTURE TACTICAL AIRCRAFT

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OUTLINE

• PAST AND CURRENT NAVAIR PROGRAMS IN AGENT INTERFACES

  - Smart Cockpit Controller (SCC) :1997-1999
  - Active Network Guidance for Emergency Logic (ANGEL)
  - Dynamic Task Allocation (DTA) :2001-2004

• PROGRAM LESSONS LEARNED

• AGENT INTERFACE TECHNOLOGY GAPS / AREAS FOR RESEARCH
Smart Cockpit Controller
System Concept

SMART COCKPIT CONTROLLER
AIRCREW SURVIVABILITY - AIRCRAFT SURVIVABILITY - MISSION PERFORMANCE

Continuous monitoring, information management, and intelligent control of airplane and crew systems

Crew Aiding

VMS

System Monitoring
Flight Recovery

Crew Escape

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## SMART COCKPIT CONTROLLER
### DECISION TABLE MODEL

#### PROBLEM AREAS

<table>
<thead>
<tr>
<th>Truth Table</th>
<th>SCC Actions</th>
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### GOALS

1. Aircrew Survival
2. Aircraft Survival
3. Mission
4. Effectiveness
SMART COCKPIT CONTROLLER EVALUATION IN NAVY’S HUMAN CENTRIFUGE / DYNAMIC FLIGHT SIMULATOR COCKPIT
SMART COCKPIT CONTROLLER
AGENT INTERFACE LESSONS LEARNED

• FORMAL METHODS ARE IMPORTANT TO CAPTURE AGENT REQUIREMENTS.
  - REQUIRE WRITTEN INPUTS WITH ASSUMPTIONS AND GOAL ATTAINMENT VALUES.
  - ESTABLISH PROCESS TO GATHER INPUTS, DISTRIBUTE INFORMATION, GET TEAM FEEDBACK, AND FINALIZE REQUIREMENTS.

• PRODUCTION RULES FROM TRUTH TABLE SUCCESSFULLY DEMONSTRATED SCC DECISION / CONTROL PROCESS WITH
  - EXHAUSTIVE LARGE DATA SET
  - DISCRETE (BINARY) INPUTS

• BINARY TRUTH TABLE APPROACH TOO BRITTLE TO MANAGE PILOT-VEHICLE INTERFACE (PVI).
  - A COMBINATION OF NATURALISTIC DECISION MAKING & COGNITIVE MODELING APPROACH MAY BE MORE ROBUST
  - TIMEFRAME FOR TACTICAL DECISIONS (15 SEC - 5 MINUTE) DRIVE AGENT INTERFACE FUNCTIONALITY AND DESIGN.
OBJECTIVE:

• DEVELOP AND VALIDATE AN AIRCREW DECISION SUPPORT SYSTEM FOR NEXT GENERATION TACTICAL AIRCRAFT (F/A-18 E/F & JOINT STRIKE FIGHTER).

TECHNICAL CAPABILITY

• ASSESS CURRENT SITUATION.
• ADVICE FOR SELECTING A COURSE OF ACTION
• OPTIMIZE AIRCREW WORKLOAD THROUGH ADAPTIVE AUTOMATION
• PROTECT AIRCREW / AIRCRAFT FROM ENEMY THREATS AND TERRAIN CRASHES

EXPECTED PAYOFFS

• REDUCED AIRCREW DECISION MAKING TIME 50% RESULTING IN 50% IMPROVEMENT IN A/G & A/A TARGET Pk.
• REDUCED AIRCREW WORKLOAD AND FATIGUE 25% RESULTING IN ESTIMATED REDUCTION OF 8 AIRCREW DEATHS/YEAR.
• ESTIMATED $4 BILLION COST SAVING PER YEAR DUE TO 75% IMPROVEMENT IN AIRCREW / AIRCRAFT SURVIVABILITY.
ANGEL SOFTWARE MODULE (INTELLIGENT AGENT & DECISION TABLE)

**INTELLIGENT AGENT**
- Decision Options
- Adaptive Info. (Formats)
- Adaptive Automation
- Adaptive Interface
- Voice Query
- Task Focus
- Advice

**PRIORITY MANAGER**

**MISSION PERFORMANCE / PROBLEM PREVENTION**

**DECISION TABLE**

**PROBLEM AREAS (39)**

<table>
<thead>
<tr>
<th>V</th>
<th>•</th>
<th>ALT &lt; MDA</th>
<th>AIRCREW TASK SATURATED</th>
<th>A/C UNRECOV</th>
<th>ACTIONS</th>
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**AIRCREW / AIRCRAFT SURVIVABILITY AND PROBLEM PREVENTION**

**SHARED MEMORY**
- Input Data
- Output Actions

**ENABLING TECHNOLOGIES**
- Smart Escape System
- Auto Ground Collision Avoid. System
- Midair Collision Avoid. System
- In-Int. Caution & Warning System

**INPUT DATA**

**OUTPUT ACTIONS**
INTELLIGENT AGENT FUNCTIONALITY EXAMPLES

TARGET OF OPPORTUNITY OPTIONS

DECISION OPTIONS

ADAPTIVE INFORMATION (FORMATS)

ADAPTIVE AUTOMATION

FLIGHT SEGMENT DISPLAY INFORMATION (CRUISE EN ROUTE)

* FULL FLIGHT AUTO.
* EMERGENCY PROCEDURES

ADAPTIVE INTERFACE

VOICE QUERY

TASK FOCUS

ADVICE

PRIORITY MANAGER

RADIO CALL TO DEPARTURE CONTROL: BY SPEECH RECOG.

“TIME TO GO TO TARGET”

FOCUS ON RIGHT ENGINE FIRE PROCEDURES

ENEMY MISSILE IN FLIGHT

“TIME TO GO TO TARGET”

FOCUS ON RIGHT ENGINE FIRE PROCEDURES

ENEMY MISSILE IN FLIGHT

RADIO CALL TO DEPARTURE CONTROL: BY SPEECH RECOG.
Intelligent Agent
Based on a Knowledge Framework

(iGEN Cognitive Modeling Tools)

- Expert oriented
- Declarative knowledge
  - multi-panel blackboard, with semantic links
- Procedural knowledge chunks (cognitive tasks)
  - compiled goal hierarchies
  - read and modify declarative blackboard
- Perceptual demons
  - self-activating encoding rules
- Action knowledge
- Meta-Knowledge
  - Knowledge-applicability contexts (task triggers)
  - Situational priority
Expertise Components

THE OUTSIDE WORLD

visual & auditory cues
physical & verbal actions

Sensation & Perception

Motor Actions

Extended Working Memory

Cognition

The ‘inside’ world

The OUTSIDE WORLD

visual & auditory cues
physical & verbal actions

Sensation & Perception

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Extended Working Memory

Cognition

The ‘inside’ world
Intelligent Agent Functional Layers

Executive Layer
- Adaptive Automation
- Decision Options
- Adaptive Information
- Adaptive Interface
- Voice Query
- Task Focus
- Advice

Control Layer
- High-Level
- Oversight
- Courses of Action
- Recommendations
- Low-Level
- Performance
- Individual Actions
- Automation

EXAMPLES
- Situation Assessment
- Context Evaluation
- Decision Making
- Task Prioritization
- Task Monitoring
- Task Selection

EXAMPLES
- Aircrew monitoring
- System monitoring
- Task performance
- Procedure prioritization
- Procedure performance
- Procedure monitoring
- Application control
- Environmental feedback

Decision Table
PVI
Cockpit Simulator
Enabling Tech₁
Enabling Tech₂
How It Works: Executive Layer

- Monitor to Ensure A/C at Right Place at Right Time
- Monitor Flight Control (e.g., Attitude; or Aviate)
- Maintain Tactical Picture
- Monitor Each Phase of Flight
- Monitor Threat Detection and Defense
- Monitor Enabling Subsystem Actions
- Monitor Pilot Actions
- Monitor System Checks
- Handle Pilot Queries to PVI
- Provide ADSS Functionality on Command from Decision Table
How It Works:
Control Layer

- Declarative Knowledge in Blackboard
- Procedural Knowledge in Methods
- Meta-Knowledge about Procedures in Blackboard
- Decisions in Goal Preconditions and Determines
- Demons Record Observed Aircrew Actions in Blackboard
- Expectations Posted in Blackboard by Tasks
  - Expected Procedures
    - Expected Action Sequences
  - Expected Threats from Mission Planning (Initialized at Start)
  - On-the-Fly Expectations from Real-Time Info
    - Threats Targets (New, Changed, Moved, Dropped, Destroyed,...)
      - Friendly Forces, Allied Forces, Opposing Forces, Others...
- Ensure Timely Actions (either by aircrew or agent)
  - Monitor, Remind and Assist (with PVI), or Automate
Functional Layers
Example

Executive Layer

1. Assess aircraft status.
2. Maintain knowledge of current mission situation.
3. Monitor / assess knowledge about flight segments (e.g., alt., speed, mode, previous state, threats).
4. Hypothesize about and decide on current flight.

Control Layer

- Display Cruise En Route information.
- Monitor aircraft status.
- Monitor aircrew performance.
- Execute Cruise En Route

Context Evaluation For Flight Segment Determination

Initiate Current Flight Segment (e.g., Cruise En Route)

Adaptive Information

Decision Table

PVI

Cockpit Simulator

Enabling Tech₁

Enabling Techₙ
1. **Need computer tools**, which support all knowledge engineering phases to reduce labor/time requirements.

   - Tools would include the capability to perform:
     (a) agent domain definition
     (b) Knowledge elicitation (i.e., data capture and data management)
     (c) functional and detail requirement specification
     (d) interface design

   - Tools need to support requirement definition through reliability & validation including auto coding.

2. Behavioral & cognitive task analyses are beneficial in establishing initial decision support system requirements. However, due to changing conditions (e.g., missions, tactics, weather), **extensive usability testing and refinement** is required for the decision support system to be robust.
3. In representing and controlling the pilot-vehicle interface a combination of naturalistic decision making & cognitive modeling was more robust than a binary state approach.

4. Timeframe for decisions (e.g., 15 sec versus 5 minutes) drive agent interface functionality and design. Decision timeframe also determines types of decision support (e.g., naturalistic, adaptive automation, and full automation).

5. Need to develop a cognitive model taxonomy that identifies the advantages / disadvantages / domains of use / etc. of current cognitive models (e.g., ACT-PM, SOAR, iGEN) along with new models as they are developed. Taxonomy will aid in model selection.
ANGEL GOALS - Maintain Optimum Mission Performance, Prevent Problems, Improve Aircrew and Aircraft Survivability

ANGEL provides pilot with ‘virtual copilot’ with three levels of support (goals)

Task Saturation

Loss of Situational Awareness
Increased Mishaps

Information Management Tasks

Peak Performance

WWII Vietnam Today Future Cockpit

G E L provides pilot with ‘virtual copilot’ with three levels of support (goals)
ANGEL SOFTWARE MODULE (INTELLIGENT AGENT & DECISION TABLE)

INTELLIGENT AGENT

- DECISION OPTIONS
- ADAPTIVE INFO. (FORMATS)
- ADAPTIVE AUTOMATION
- ADAPTIVE INTERFACE
- VOICE QUERY
- TASK FOCUS
- ADVICE

PRIORITY MANAGER

MISSION PERFORMANCE / PROBLEM PREVENTION

INPUT DATA

OUTPUT ACTIONS

OUTPUT ACTIONS

SMART ESCAPE SYSTEM

AILSS

PVI:
- VOICE REC.
- 3D AUDIO
- HMD

AUTO GROUND COLLISION AVOID. SYSTEM

MIDAIR COLLISION AVOID. SYSTEM

INTEG. CAUTION & WARNING SYSTEM

SHARED MEMORY

ENABLING TECHNOLOGIES

AIRCREW / AIRCRAFT SURVIVABILITY AND PROBLEM PREVENTION

INPUT DATA

OUTPUT ACTIONS

OUTPUT ACTIONS

PROBLEM AREAS (39)

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<tr>
<td>0 0 0 0 0 1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

ACTIONS

- EJECT PROMPT
- AUTOMATE SELECTED TASKS
  - AGCAS
  - AUTO. SEL. TASKS

MISSION PERFORMANCE / PROBLEM PREVENTION

AIRCREW / AIRCRAFT SURVIVABILITY AND PROBLEM PREVENTION
CURRENT ANGEL LESSONS LEARNED

• REQUIREMENTS DEVELOPMENT FOR DECISION TABLE MATRIX WAS VERY LABOR AND TIME INTENSIVE.

• NEED COMPUTER TOOLS WHICH SUPPORT ALL KNOWLEDGE ENGINEERING PHASES TO REDUCE LABOR / TIME DEMANDS.

- COMPUTER TOOLS CAN BE MOST BENEFICIAL IN ASSisting IN DATA CAPTURE, AND DATA MANAGEMENT.

- TOOLS NEED TO SUPPORT REQUIREMENTS DEFINITION THROUGH RELIABILITY & VALIDATION INCLUDING AUTO-CODING.

- ANGEL PROGRAM PRODUCED A GENERAL SOFTWARE PROGRAM TO CHECK RELIABILITY & VALIDITY OF BINARY DECISION MATRIX (KAAT TOOL AVAILABLE ON CD-ROM).
• **RESEARCH OBJECTIVES:**
  
  (1) **To Develop a Skill-Based Paradigm Including Agent Learning** for Human-Agent Dynamic Task Allocation.

  (2) **To Empirically Assess, Revise and Validate** the Dynamic Task Allocation Skill-Based Paradigm.

• **LONG TERM GOALS:**

  (1) **Understand the Processes Involved in Performing Dynamic Task Allocation** Between a Human and an Intelligent Agent.

  (2) **Understand How Agent Learning Can Be Applied** in Human-Agent Dynamic Task Allocation.

• **PRODUCTS:**

  (1) A Skill-Based Paradigm for Human-Agent Dynamic Task Allocation, (2)

  Empirical Evaluation and Validation of the Paradigm and (3) Principles and Guidelines for Human-Agent Dynamic Task Allocation.
**Technical Approach**

**COMPONENTS OF SKILL-BASED PARADIGM**

### Multiple Flight Test Skill Battery (MFTS)

**Skills**
- **Psychomotor**
- **Auditory**
  - Sound/Localization
  - Auditory Attention
- **Visual Discrimination**
- **Cognitive**
  - Reasoning
  - Information ordering, inductive reasoning, deductive reasoning, numerical reasoning
  - Conceptual
  - Visualization
  - Spatial Orientation
  - Memorization
- **Speed Loaded**
  - Perceptual Speed
  - Time Sharing

### Agent Functionality

- **What** to automate/areas for decision aiding.
- **How** to automate and provide decision aiding.
- **When** to provide automation/decision aiding.

### Agent Learning Techniques

**Addresses:**
- Dynamic human-agent task prioritization.
- Human-agent feedback.
- Task control back to human

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1. **NEED COMPUTER TOOLS**, WHICH SUPPORT ALL KNOWLEDGE ENGINEERING PHASES TO REDUCE LABOR / TIME REQUIREMENTS.

   - TOOLS INCLUDE: (A) AGENT DOMAIN DEFINITION  
     (B) KNOWLEDGE ELICITATION  
     (C) FUNCTIONAL & DETAIL REQ. SPEC.  
     (D) INTERFACE DESIGN  
     (E) RELIABILITY & VALIDATION

2. **NEED TO DEVELOP A COGNITIVE MODEL TAXONOMY** THAT IDENTIFIES THE ADVANTAGES / DISADVANTAGES / DOMAINS OF USE / ETC. OF CURRENT COGNITIVE MODELS (E.G., ACT-PM, SOAR, IGEN) ALONG WITH NEW MODELS.

   - TAXONOMY WOULD AID IN MODEL SELECTION DURING DECISION SUPPORT SYSTEM DEVELOPMENT.