

**AFRL-VA-WP-TP-2003-327**

**VALIDATION AND VERIFICATION OF  
INTELLIGENT AND ADAPTIVE  
CONTROL SYSTEMS (VVIACS)**



**James Buffington**

**SEPTEMBER 2003**

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# *Validation and Verification of Intelligent and Adaptive Control Systems (VVIACS)*

**James Buffington  
September 17, 2003**

2nd AIAA "Unmanned Unlimited" Systems, Technologies, and  
Operations—Aerospace, Land, and Sea Conference and Workshop & Exhibit  
San Diego CA

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# OUTLINE



- INTRODUCTION
- APPROACH
- STATUS
- Q&A



# TEAM



Team Member (Expertise)	VIACS Assessment	VIACS Development	VIACS Evaluation
LM (Flight Certification)	High	Moderate	Low
SSCI (Autonomous Control)	High	Moderate	Low
GEGR (V&V)	High	Moderate	Low
Prof. Krogh (V&V)	High	Moderate	Low

### Participation Level

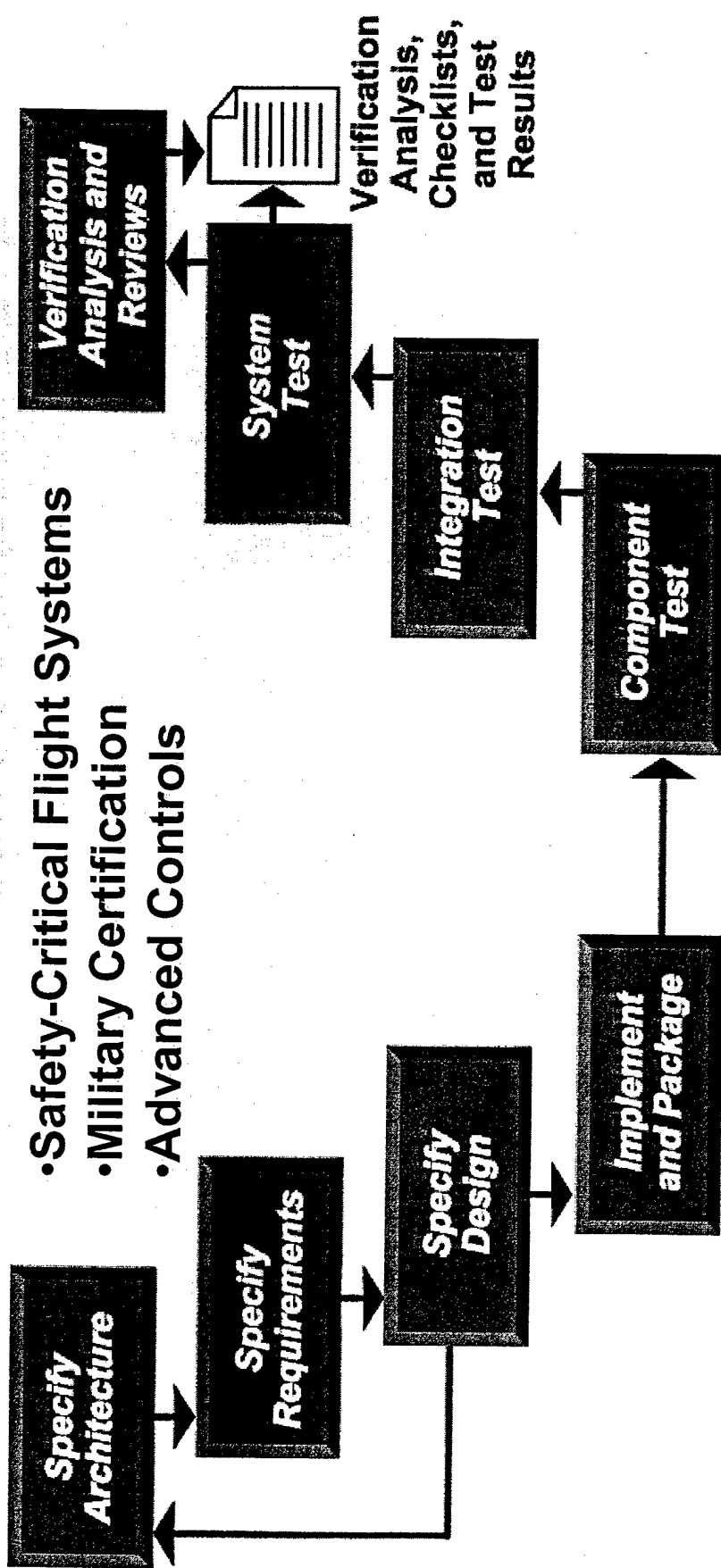
High
  Moderate
  Low

A02-04851038

- Vince Crum – AFRL - Government PM
- Jim Buffington – LM Aero - Contractor PM
- Clinton Plaisted – LM M&FC
- Prasanta Bose – LM M&S
- Bruce Krogh – Carnegie Mellon University
- Tim Johnson – General Electric Global Research
- Ravi Prasanth – Scientific Systems Company, Inc
- Peter Stanfill – LM Aero
- Greg Tallant – LM Aero
- Barry Frazier – LM M&FC
- Hunt Sutherland – General Electric Global Research



# SCOPE



- Safety-Critical Flight Systems
- Military Certification
- Advanced Controls

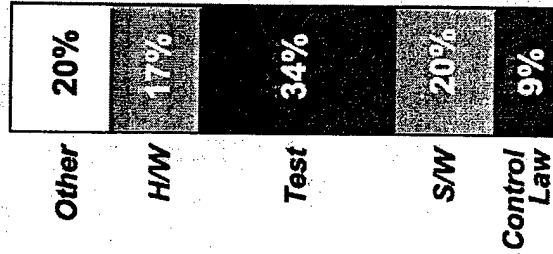
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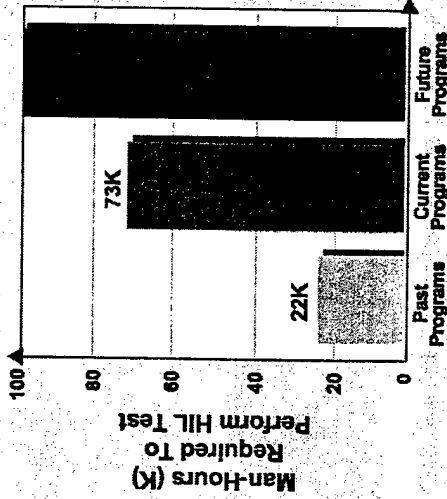
# MOTIVATION



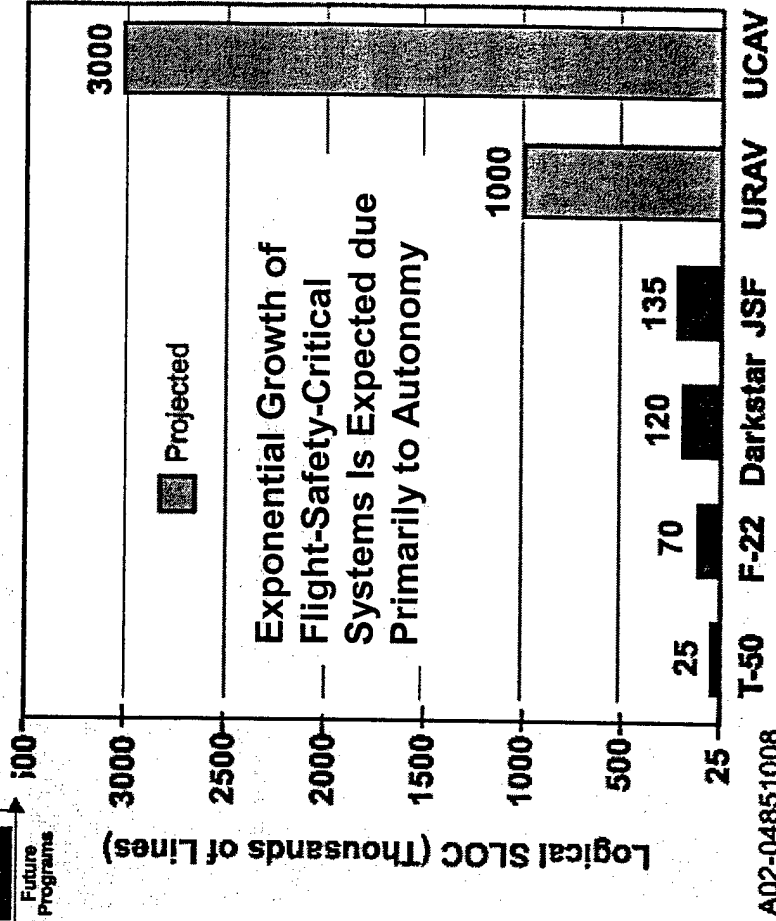
**Costs of Design and Testing Dominate Current Flight-Safety-Critical Systems**



*Typical Flight Critical System Development Cost Model*  
A02-04851004



**Future Military Program Testing Hours Are Forecast to Triple**



A02-04851008



## PURPOSE



### **GOAL:**

*Enable affordable development of future safety-critical flight systems with prescribed levels of safety and reliability.*

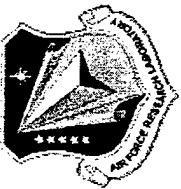
### **OBJECTIVE:**

*Study, develop, and demonstrate effective V&V technologies for advanced safety-critical control system flight certification.*

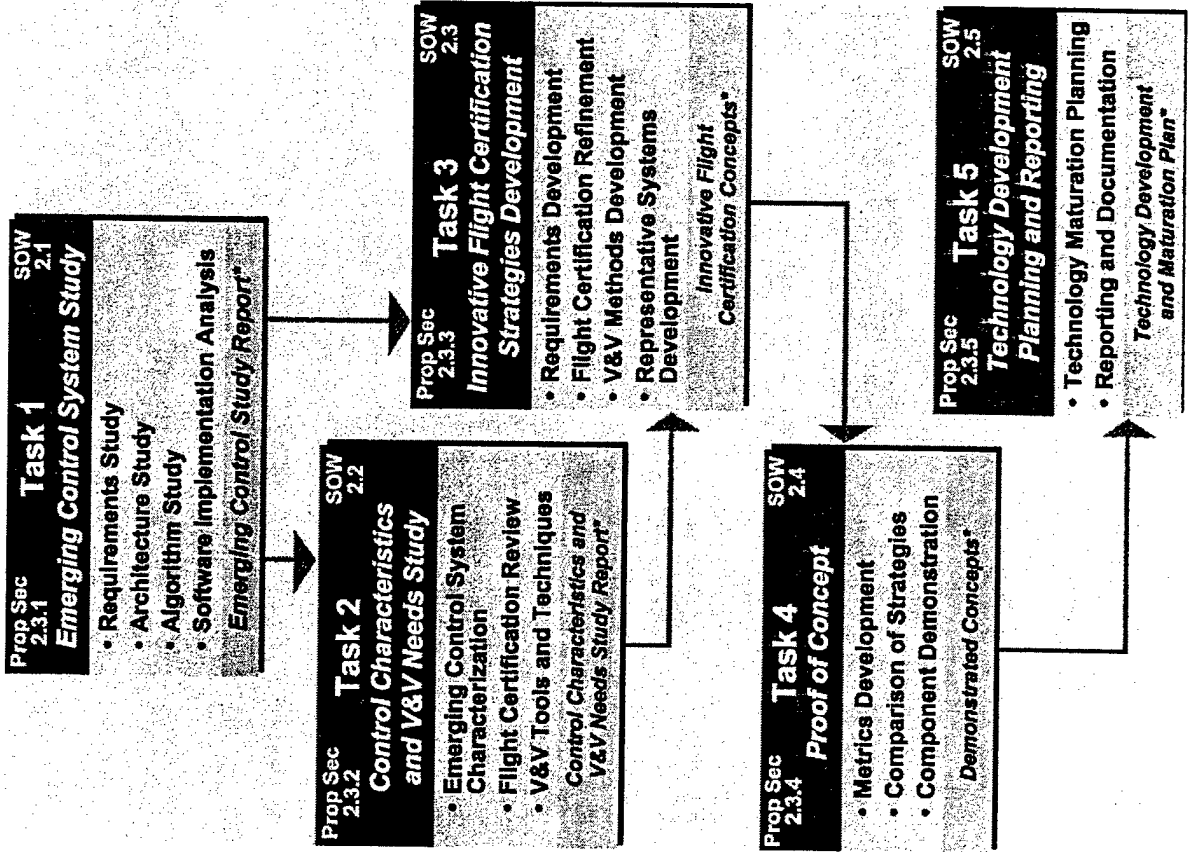
- Classify emerging safety-critical control systems according to fundamental attributes*
- Develop and demonstrate preliminary V&V strategies that focus on critical flight certification schedule and cost points*
- Identify high-payoff V&V process, tool, and method technologies for further development*

### **APPROACH:**

- Use Extensive Experience Base and Diverse Team to Develop Innovative Concepts*
- Evaluate Concepts in Realistic Framework to Maximize Transition Success*



# TASKS





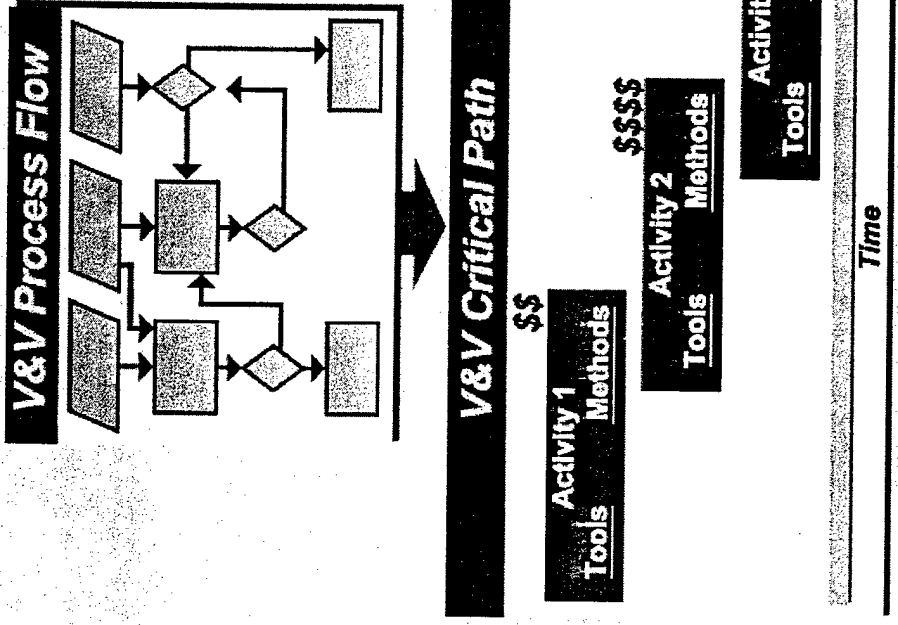
# ASSESSMENT



- Emerging Control System Study
- Control System Characterization

Control System	Functional/Architectural Attributes										Flight Certification/V&V Needs, Deficiencies									
	Adaptive	Learning	Decision Making	Predictive	Cooperative	Optimization	Reasoning	Integrated	Distributed	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
REXTONE	✓																			
SCARF					✓															
CMUS		✓																		
ITAC																				
AGCAS																				
Auto ACAS																				
Intelligent Control	✓																			
ANAS																				
SEC																				
REACT																				
RTIP																				
TBD																				
TBD																				
TBD																				

## • V&V Needs Study

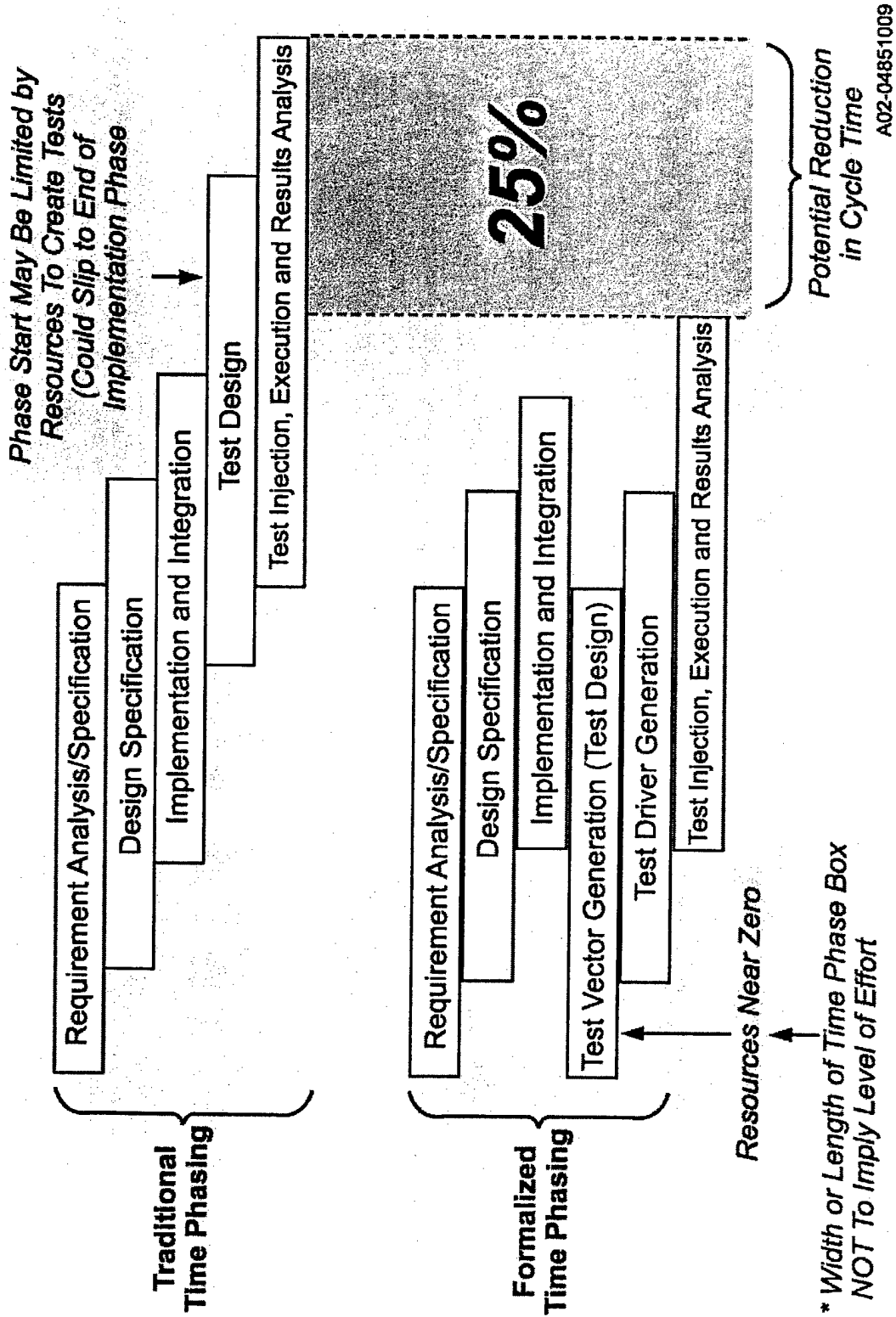


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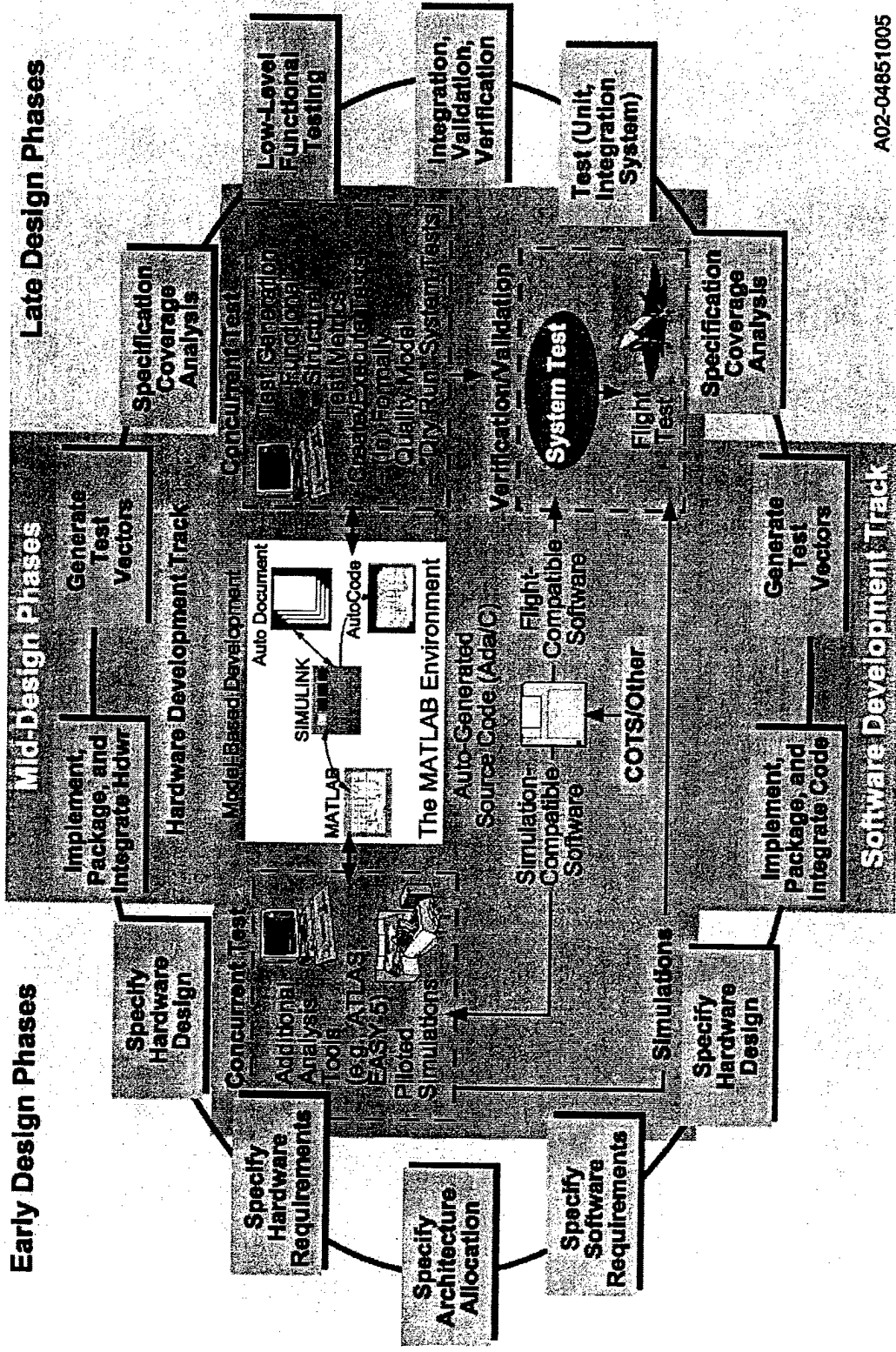
# DEVELOPMENT - Processes



## • Process Models



# DEVELOPMENT - Methods



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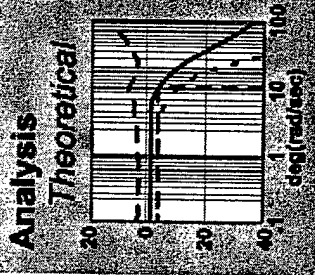


# EVALUATION - Proof of Concept



## Metric Definition

- Flight Safety
- S/W Dev Cost
- LCC
- Fit Cert Cost
- Fit Cert Effort
- Others TBD

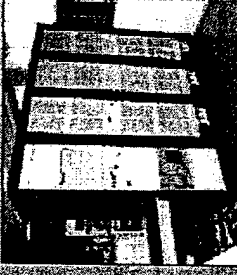


Analysis Theoretical

Simulation



Experimentation



## Assessment

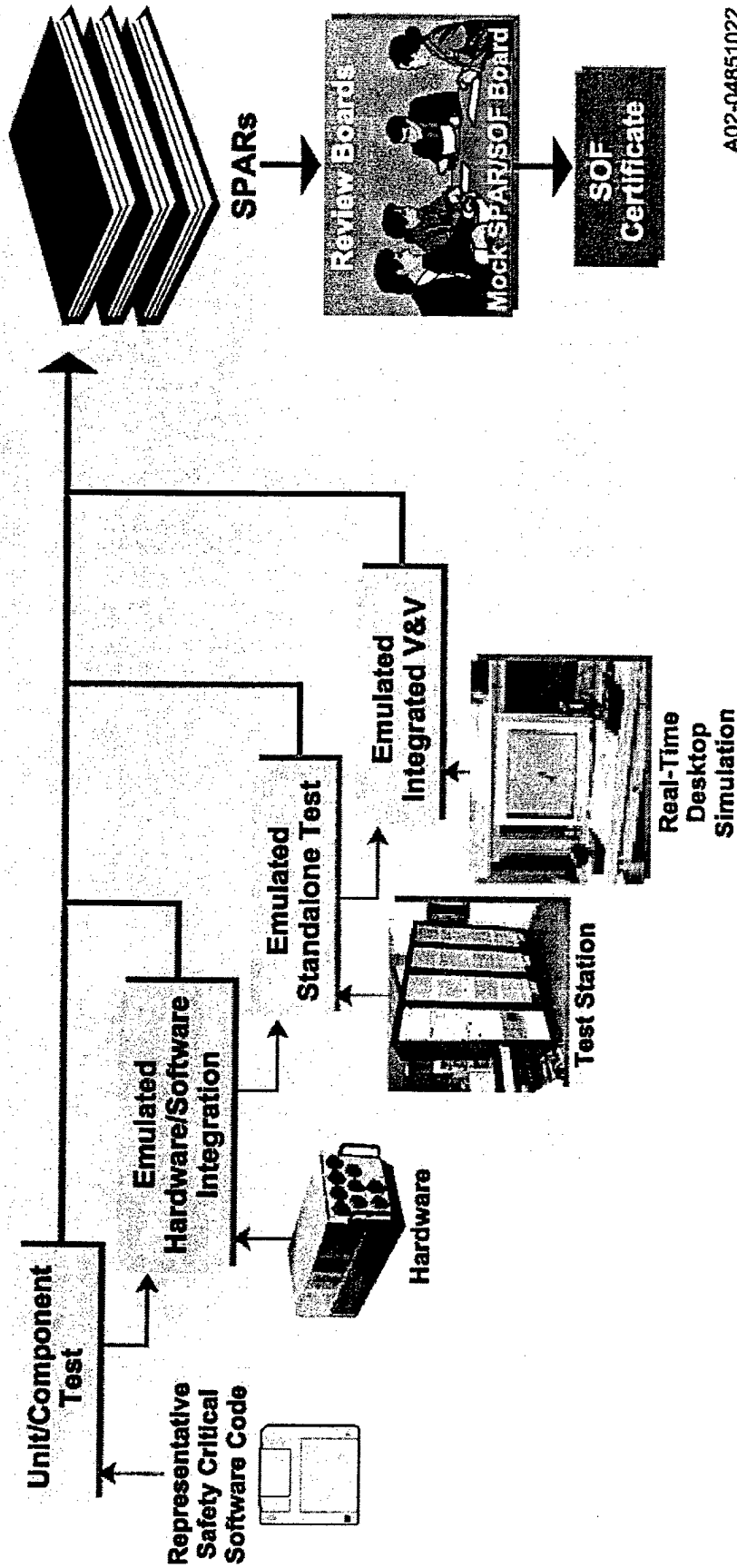
Innovative Flight Certification Concept	V&V Category	Current TRL	C <sub>DEV</sub> ROM S/W Dev Cost (\$M)	ROM Certification Cost (\$M)	Transition Metrics		Performance Metrics								Cost-Benefit Metrics			R <sub>T</sub> Technical Risk	Score	Rank		
					Current Systems	Next-Generation Systems	Feasibility	Flight Safety	Resource Utilization	Software Defect Density	Test Coverage	Design Cycle Time	Touch Labor Reduction	Product Size	Cost	Benefit	CBR					
Concept A	Proc, Tool	5	5	7.5	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	1
Concept B	Tool, Meth	6	6	9	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	2
Concept C	Meth	5	12	36	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	3
Concept D	Tool	4	6	9	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	4
Concept E	Tool	6	1	1.5	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	5
Concept F	Proc	4	8	12	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	6
Concept G	Proc	5	120	180	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	7
Concept H	Proc, Meth	3	6.5	7.56	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	8
Concept I	Proc, Tool, Meth	3.5	38	94	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	9
Concept J	Proc, Tool, Meth	3	28	37.5	100	100	100	25	100	25	100	100	100	100	100	100	100	100	100	0.1687	0.318	10

**Most Promising Concepts for Demonstration**

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# EVALUATION - Safety of Flight Certification Model



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# EVALUATION - Planning

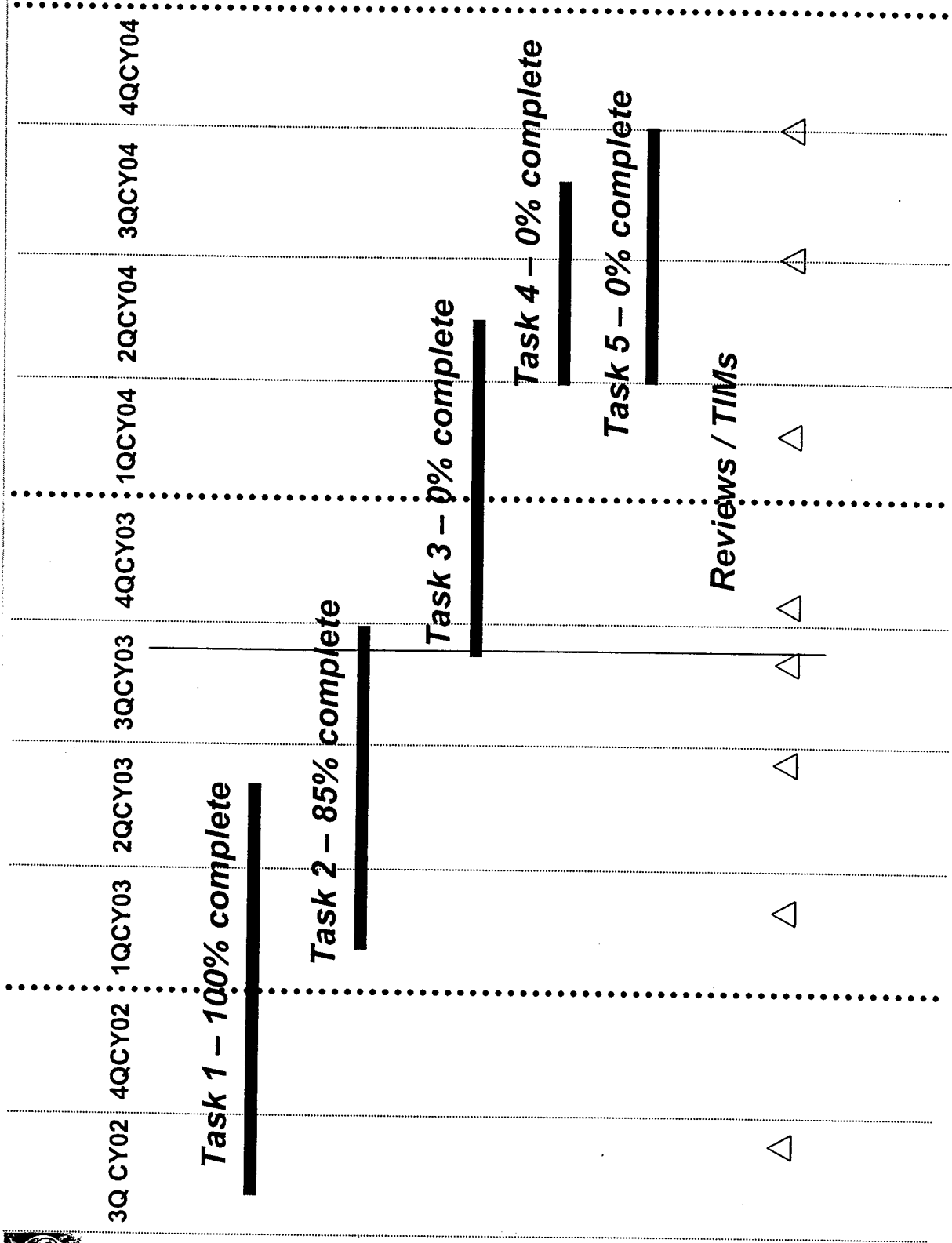
## Tech Risk Level

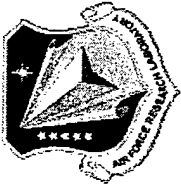
High	Significant	Moderate	Minor	Low	CY	Milestones
1. Exit Criteria ①	2. Exit Criteria ②	3. Exit Criteria ③	4. Exit Criteria ④		1999	MS1
TRL 3	TRL 4	TRL 5	TRL 6		2000	MS2
1. Activities & Cost	2. Activities & Cost	3. Activities & Cost	4. Activities & Cost		2001	MS3
					2002	MS4
					2003	MS5
					2004	MS6
					2005	

A02-04851020



# STATUS – Program Schedule





# STATUS - Database Tool



Microsoft Access - [Main Menu: Form]

File Edit View Insert Format Records Tools Window Help

Type a question for help

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Validation & Verification of Intelligent and Adaptive Control Systems

TECHNICAL

GLOSSARY

Task 1 - Emerging Control Systems Study

Task 2 - Control Characterization and VV Needs

Quit Access

Record: 14 of 1

Form View

NUM



# STATUS - Control System Database

## Task 1 Database



Microsoft Access - [temp] Type a question for help

File Edit View Insert Format Records Tools Window Help

Mail Menu

Project Downselect

CATEGORY	DATA FIELDS	INSTRUCTIONS	REFERENCE MATERIAL
Program Name	AUTOCAS/AGCS	Enter distinct name of program or project	
Application	Military Aircraft	Choose best selection from menu	
Time	Past	Past, Current, Planned, or Future Program	
Technology Readiness Level	7	Choose best selection from menu	TRL chart
Maturity	Prototype	Choose best selection from menu	
Information Source	Mechanization / Implementation	Level of documentation available for further study	
Releasability of Information	ITAR	Choose best selection from menu	
Emerging Control Level	Medium	Choose best selection from menu	ECL chart
Primary Approach/Attribute	Classical	Enter a few key words that describe the basis of the approach and support the Emerging Control Level	
Control Domain	Guidance	Choose best selection from menu	Control Domain chart
Autonomous Control Level	1	Choose best selection from menu	ACL spreadsheet
System State	Hybrid	Choose best selection from menu	System State chart
V/VACS Owner	LM Aero	Choose best selection from menu	
Developer	LM Aero	Enter the prime contractor of the program	
Key Words		Enter a few key words for this project	
Comments		Enter any additional comments	

Record: 14 of 40 Form View

**Primary Scoring Factors**

**Other Factors:**  
Maturity  
Developer  
Autonomy  
Application



# STATUS – Emerging Control Systems



## ECS PROJECT

### **AIMSAFE / RESTORE**

**ICARUS**

**LOCAAS**

**Enhanced GNC Algorithms**

**XACT**

**Software Enabled Control**

**EDCS F-16 Autopilot**

**Engine Control Cutoff Mode**

**Intelligent Engine Control**

**Intelligent Maintenance Advisor for Turbine Engines**

**Formation Flying Spacecraft**

## DESCRIPTION

**Integrated Management, Adaptive Control**

**Intelligent Autonomy**

**Autonomous Control**

**Dynamic Programming Optimization**

**Adaptive Failure Management**

**Optimal Trajectory Generation**

**Outer Loop Hybrid Control**

**Nonlinear Hybrid Control**

**Intelligent Failure Management**

**Model-based Health Management**

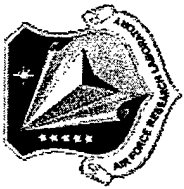
**Multi-vehicle Control**



# **STATUS - Summary**



- **Emerging Control System Study (Task 1)**
  - Completed study and organization of project data (48 projects)
  - Completed project data collection and insertion into database tool
  - Completed project data down-select to 10 Emerging Control Systems
  - Developed preliminary project glossary
- **Control Characterization and V&V Needs Study (Task 2)**
  - Developed detailed task plan
  - Review of LM Aero FC/VMS development processes and program plans
  - Developed preliminary representative time-phased critical-path representation of development process
  - Completed Control Characterization of control system projects with emphasis on Emerging Control Systems



**Q&A**



# Questions?