



Understanding the Impact of Cognitive Reference Frames on Unmanned Aircraft Operator Workload and Performance

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22 January 2016

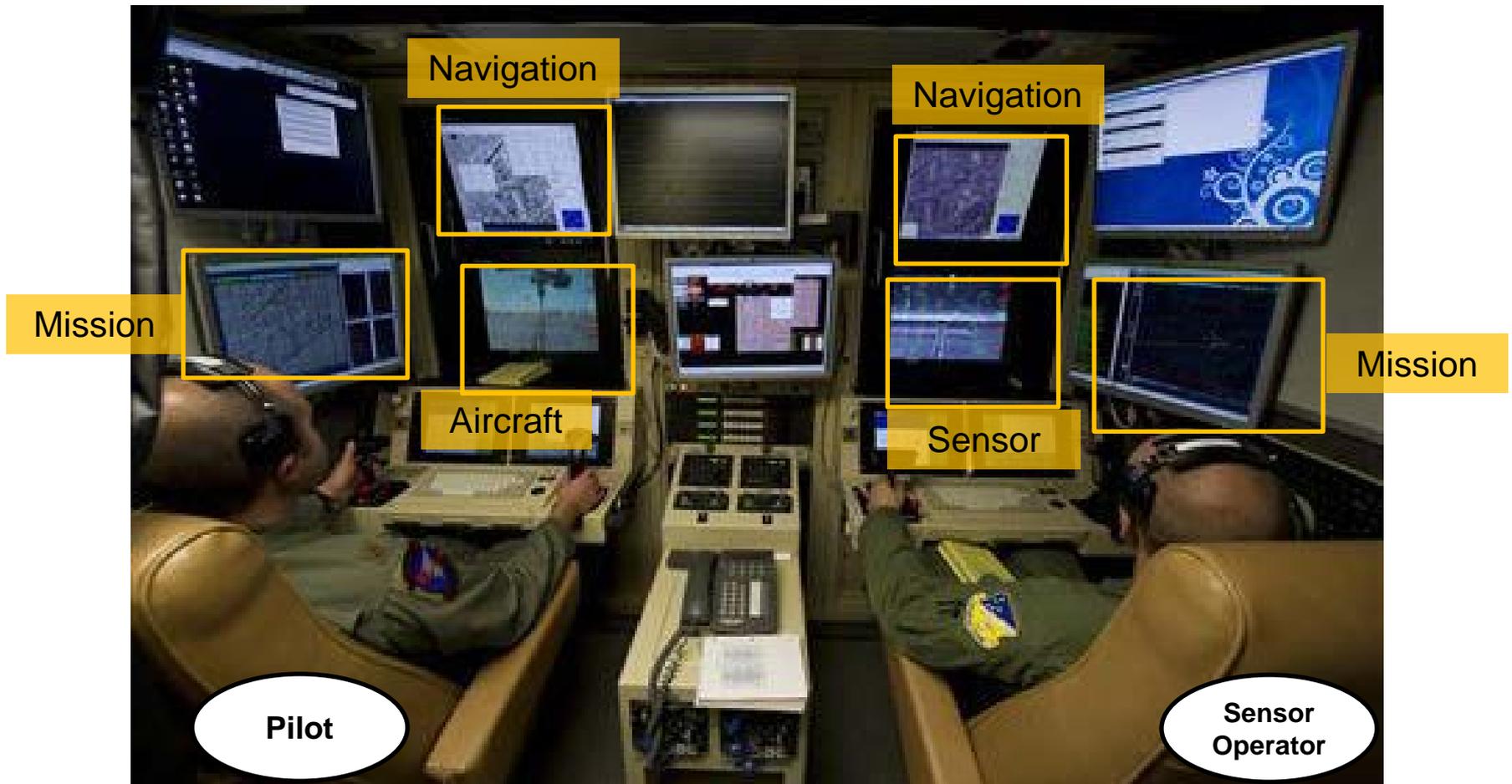


Overview

- **Motivation**
- **Experimental Methods**
 - Independent Variables
 - Dependent Variables
- **Prior Work**
- **Current Study**
- **Discussion**

Motivation

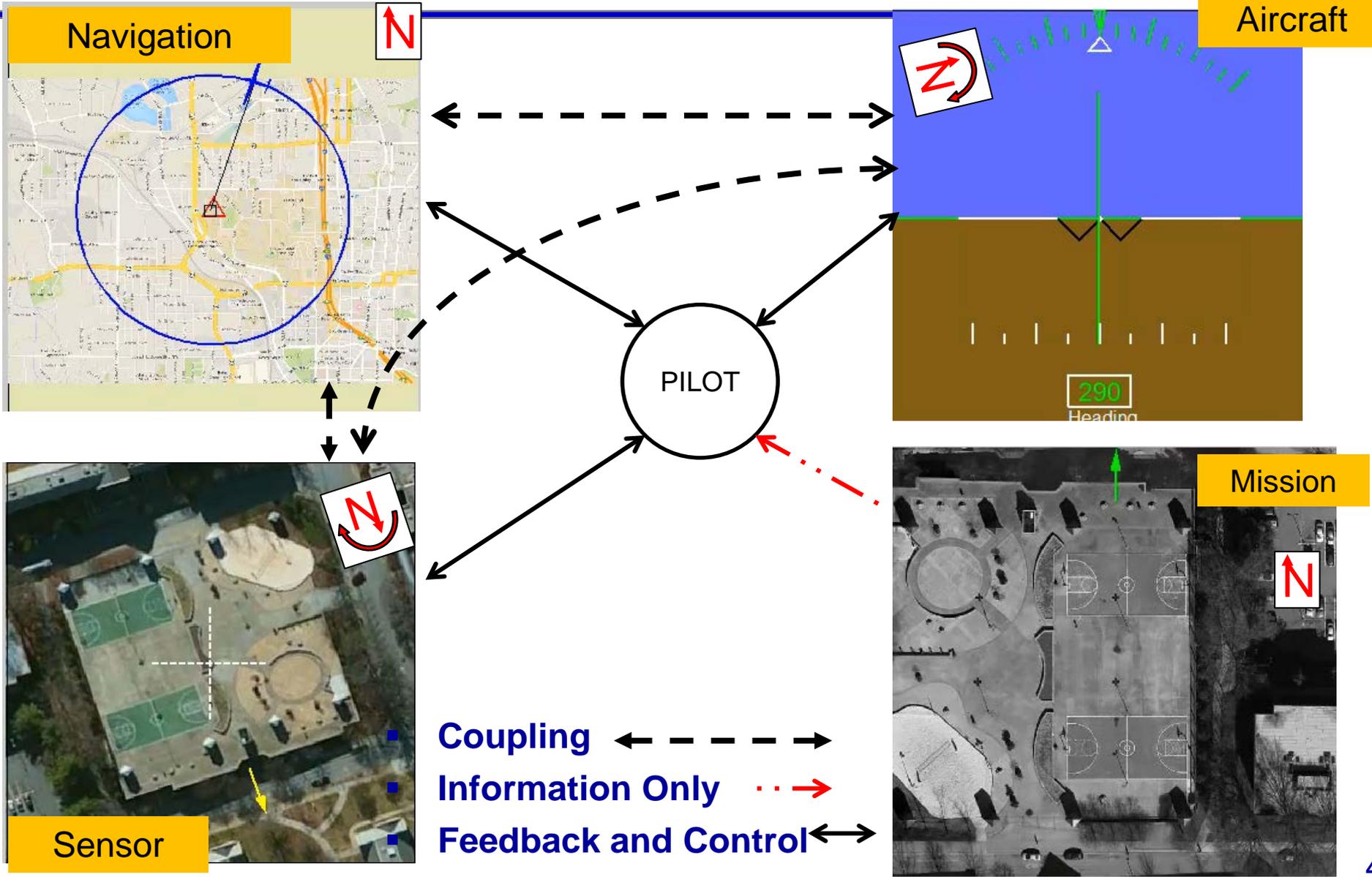
“One of the largest cost drivers in the budget of DoD is manpower” [1]



[1] DoD Unmanned Systems Roadmap FY2013 US Air Force Reaper Ground Control Station[2]

[2] Reuters

Single Operator





General Research Hypothesis

Reducing cognitive orientation time will improve multitask performance and workload during representative Unmanned Aircraft missions.

Experimental Methods

- Subjects control an aircraft and onboard video sensor
- Display configuration is varied to adjust several independent variables

The screenshot shows a flight simulator interface with four main display panels:

- Navigation Display:** A map view showing a blue circle around a red triangle representing the aircraft's current position and heading.
- Aircraft Display:** A perspective view of the aircraft's nose and cockpit area, showing a heading of 290 degrees.
- Sensor Display:** A top-down view of a basketball court with a yellow arrow pointing to a specific location on the court.
- Mission Display:** A top-down view of the same basketball court with a green arrow pointing to a specific location on the court.

Below the displays is a control panel with various settings:

- Senso... North Up
- LJS
- RJS
- 2D Bnk
- Twist
- Course Indicator
- Stop 90
- Northeast Basketball Hoop
- Trigger Light
- Direction Switch
- Reset Switch



Experimental Designs

Independent Variables

1. Reference Frame
Alignment
2. Exocentric Orientation Aids
3. Display Integration
4. Target Movement
5. Aircraft Display Removal

Controlled variables

1. Subject
2. Image Rotation Angle
3. Subject Trial Number
4. Target

Dependent Variables

Performance

1. Target Acquisition Time (ONLY for STATIONARY TARGETS)
2. Combined Track Error
3. Orientation Time

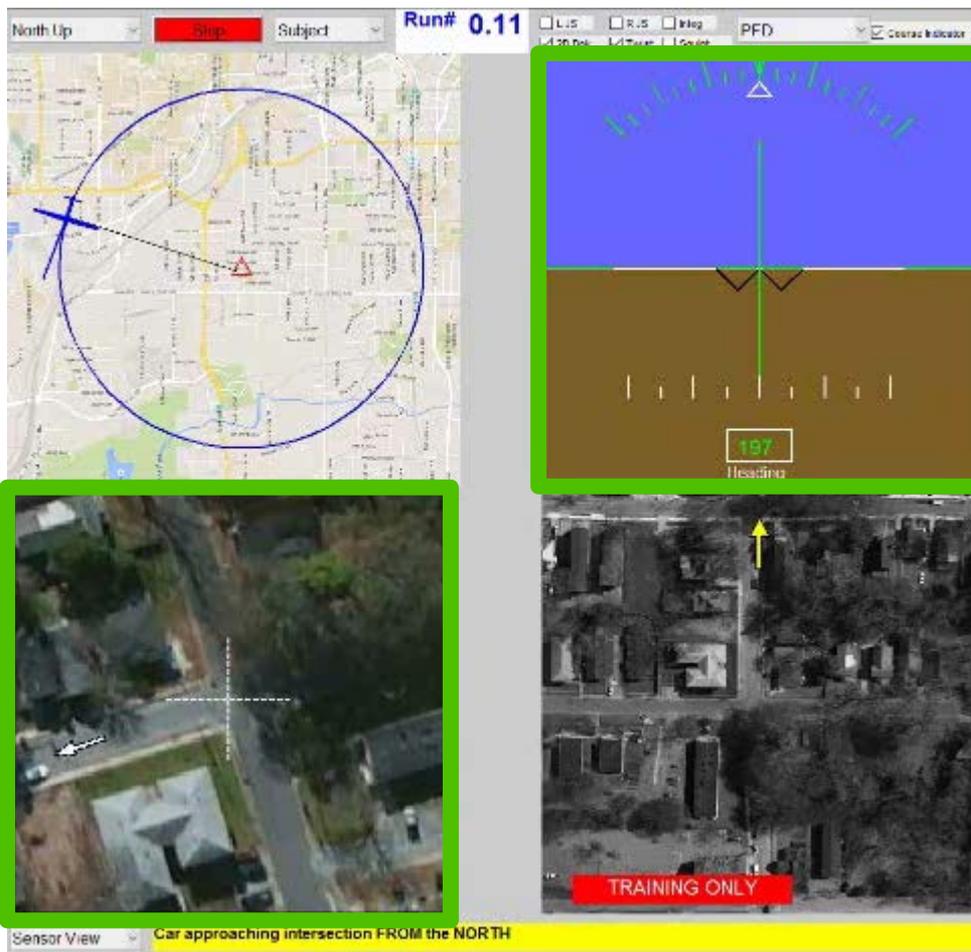
Workload

1. Secondary Workload
Measurement (Reaction Time)
2. Subjective Workload Rating

Independent Variables: Reference Frame Alignment

Misaligned

Aligned

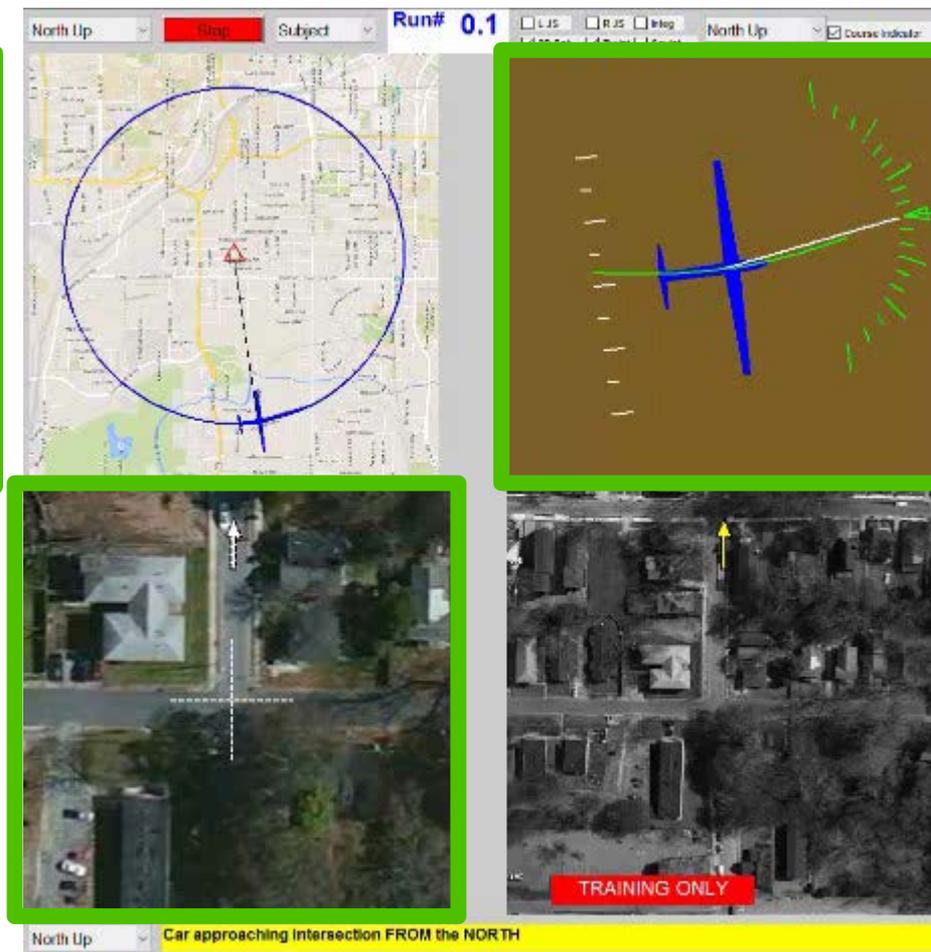


North Up Stop Subject Run# 0.11 PFD Course Indicator

197 Heading

Sensor View Car approaching intersection FROM the NORTH

Detailed description: This panel shows a simulation interface for a 'Misaligned' scenario. At the top left, a map view shows a blue circle and a red triangle. The main heading indicator (PFD) has a blue background and a green vertical line, with a green box around the number '197' and the word 'Heading'. Below it, a sensor view shows an aerial view of a car approaching an intersection from the north, with a yellow arrow pointing up. A red banner at the bottom of the sensor view says 'TRAINING ONLY'.



North Up Stop Subject Run# 0.1 PFD Course Indicator

TRAINING ONLY

North Up Car approaching intersection FROM the NORTH

Detailed description: This panel shows a simulation interface for an 'Aligned' scenario. At the top left, a map view shows a blue circle and a red triangle. The main heading indicator (PFD) has a brown background and a green line that is rotated to match the map's orientation. Below it, a sensor view shows an aerial view of a car approaching an intersection from the north, with a yellow arrow pointing up. A red banner at the bottom of the sensor view says 'TRAINING ONLY'.

Independent Variables: Exocentric Orientation Aids

**No Exocentric Orientation Aid
No "North Arrow"**

**Exocentric Orientation Aid Present
"North Arrow"**

North Up Stop Subject Run# 0.1 LJS RJS Inlog PFD 20 ft Tweak Square Course Indicator

348
Heading

Sensor View Car approaching intersection FROM the SOUTH

North Up Stop Subject Run# 0.11 LJS RJS Inlog PFD 20 ft Tweak Square Course Indicator

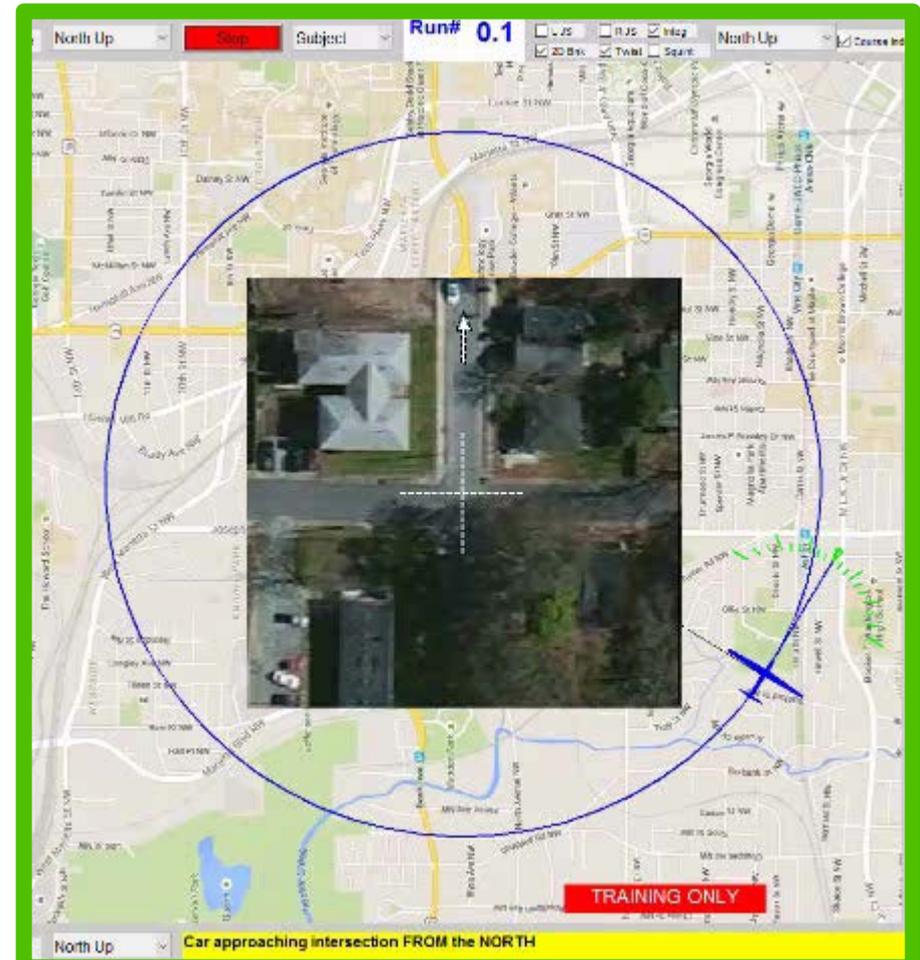
197
Heading

Sensor View Car approaching intersection FROM the NORTH

Independent Variables: Display Integration

Separate Displays

Integrated Display



Independent Variables: Target Movement

Stationary Target

Moving Target

North Up Stop Subject Run# 0.11 L/S R/S Inlog PFD Course Indicator
 2D Brk Twist Squint

197
Heading

Sensor View Car approaching intersection FROM the NORTH

TRAINING ONLY

North Up Stop Subject Run# 0.11 L/S R/S Inlog PFD Course Indicator
 2D Brk Twist Squint

299
Heading

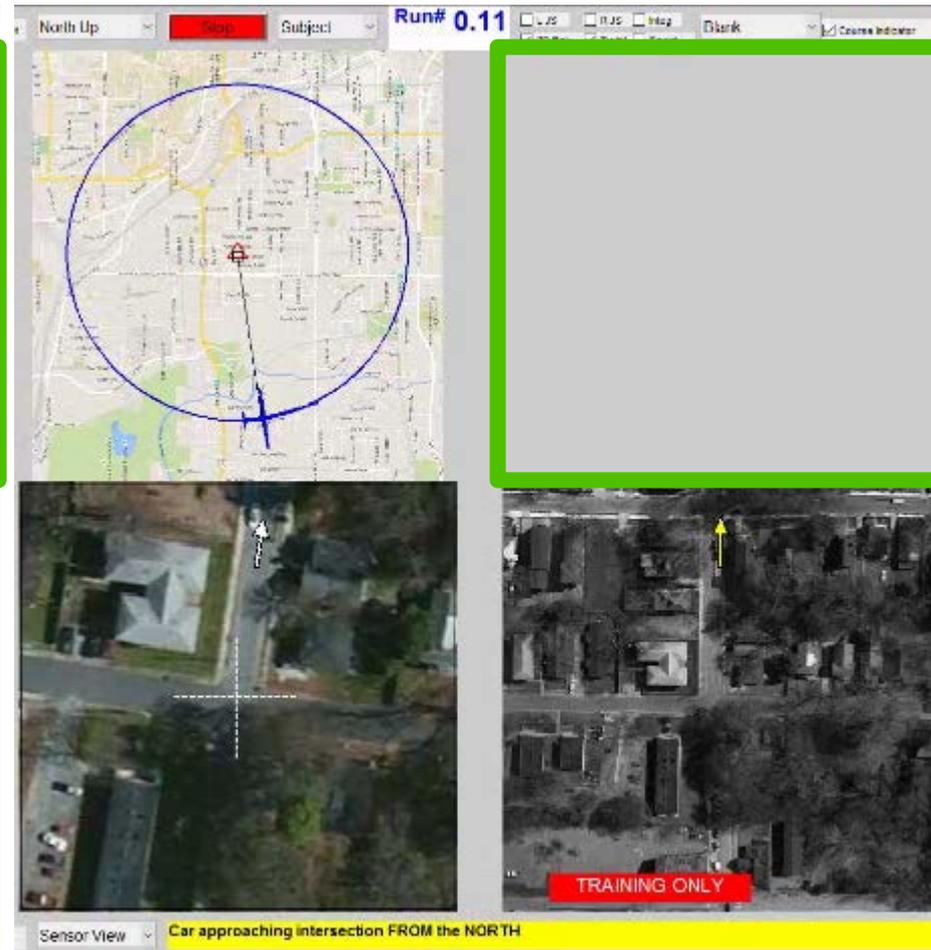
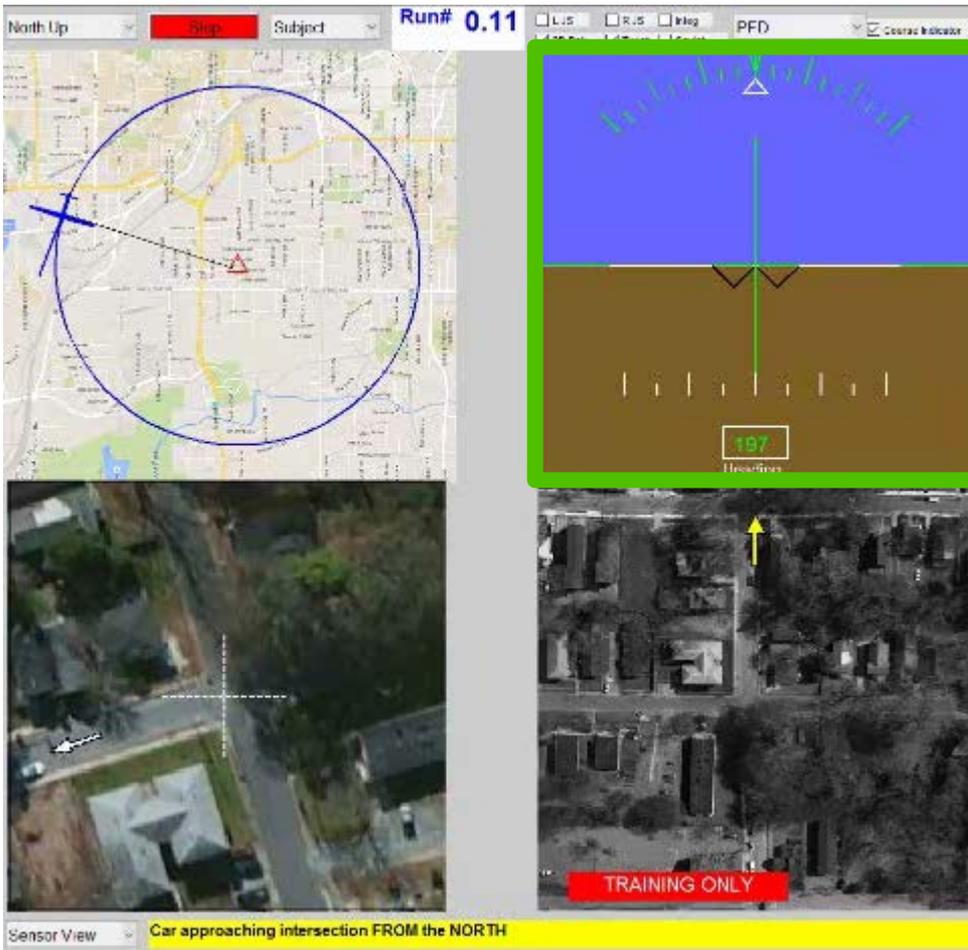
Sensor View Car approaching intersection FROM the WEST

TRAINING ONLY

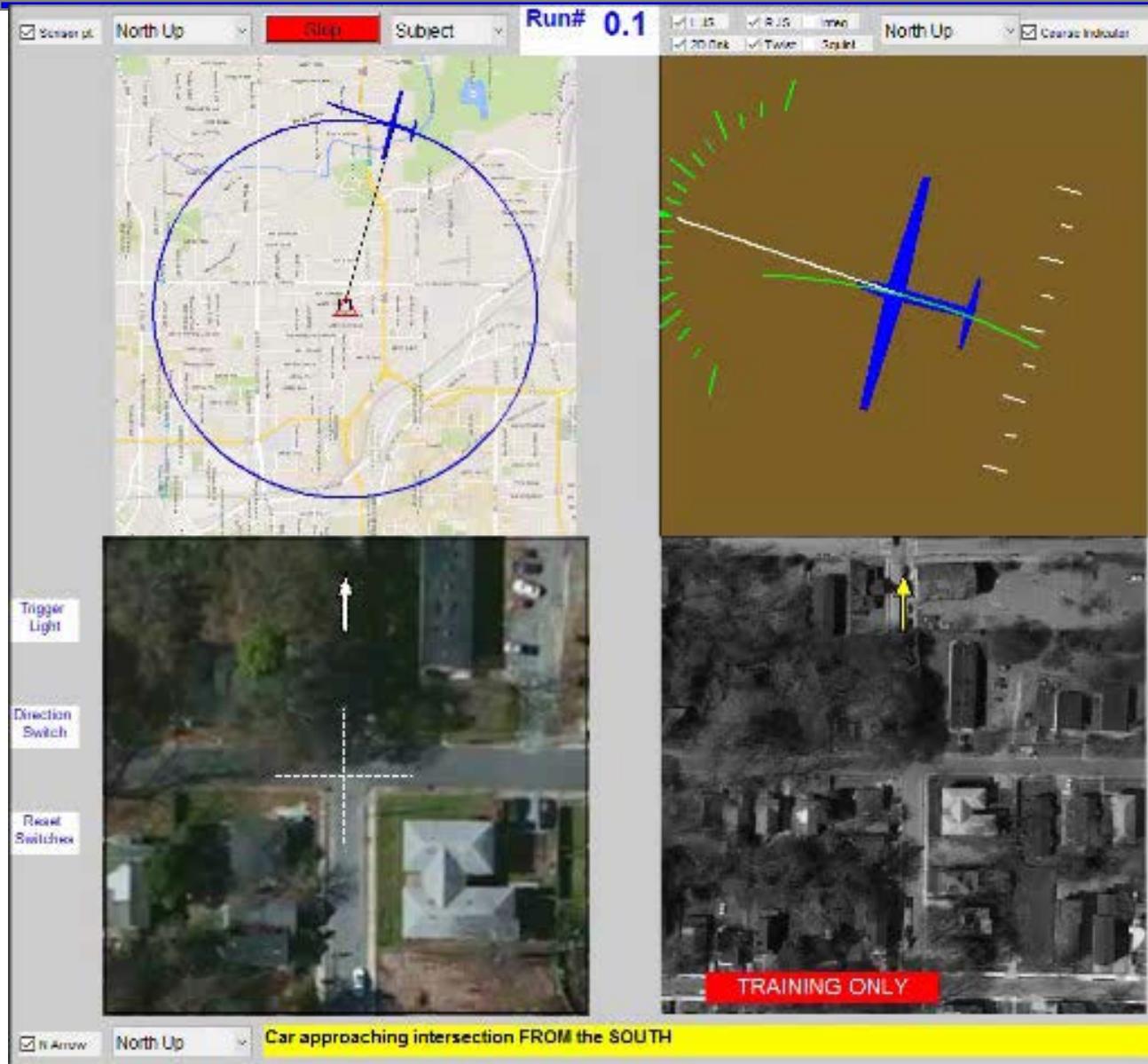
Independent Variables: Removing Aircraft Display

**Aircraft Display
“PFD”**

**Aircraft Display Removed
No “PFD”**



Dependent Variables



Dependent Variables

Performance

1. Target Acquisition Time (ONLY for STATIONARY TARGETS)
2. Combined Track Error
3. Orientation Time

Workload

1. Secondary Workload Measurement (Reaction Time)
2. Subjective Workload Rating



Prior Work: Initial Simulator Study

- **Independent Variables**
 - Reference Frame Alignment
 - Exocentric Orientation Aids
- **Display Configurations**

	Display Configuration			
Display	A	B	C	D
Aircraft	Track-Up	Track-Up	Track-Up	North-Up
Navigation	North-Up	North-Up	North-Up	North-Up
Sensor	Sensor-View	North-Up	Sensor-View	North-Up
Mission	North-Up			
# Reference Frames	3	2	3	1
Orientation Aid	Yes	Yes	No	No
Integrated	No	No	No	No



Prior Work: Initial Simulator Study

Pairwise Comparisons

- Independent Variables
 - Reference Frame Alignment
 - Exocentric Orientation Aids

- Results

36 subjects 2-sided student t-test $t_{crit} = 2.6$ 1-sided p-value			Reference Frame (RF) Alignment			Exocentric Orientation Aid (OA)
			2 RF \neq 1 RF Disp B \neq D	3 RF \neq 2 RF Disp C \neq B	3 RF \neq 1 RF Disp C \neq D	No OA \neq OA Disp C \neq A
Performance ²	Orientation Time ¹	t*	-0.620	13.21	14.56	4.57
		p-value	0.73	1.8e-15	1.1e-16	2.9e-5
	Target Acquisition Time ¹	t*	1.95	5.62	6.27	0.792
		p-value	0.030	1.2e-6	1.7e-7	0.22
	Combined Track Error ¹	t*	-4.62	4.79	1.79	1.60
		p-value	0.99997	1.5e-5	0.041	0.060
Workload ²	Subjective Workload Rating	t*	-0.978	5.56	5.33	3.97
		p-value	0.833	1.5e-6	2.9e-6	1.7e-4
	Reaction Time ¹	t*	0.579	3.74	3.87	1.44
		p-value	0.28	0.00033	0.00023	0.079

¹Transformed variables



Prior Work: Initial Simulator Study

- **Independent Variables**
 - Reference Frame Alignment
 - Exocentric Orientation Aids

- **Conclusions**
 - Demonstrated effectiveness of sensor video Reference Frame Alignment to improve each performance and workload measurement.
 - Demonstrated effectiveness of Exocentric Orientation Aids to improve Orientation Time.

- **Unexpected Observations**
 - Currently accepted practice (Exocentric Orientation Aids) did not improve target acquisition time
 - Aircraft display reference frame alignment did not improve performance or workload measurements



Current Experiment Design

Independent Variables

1. Reference Frame Alignment
2. Display Integration
3. Target Movement

Controlled variables

1. Subject
2. Image Rotation Angle
3. Subject Trial Number
4. Target

Dependent Variables

Performance

1. Target Acquisition Time (ONLY for STATIONARY TARGETS)
2. Combined Track Error
3. Orientation Time

Workload

1. Secondary Workload Measurement (Reaction Time)
2. Subjective Workload Rating



Current Study Display Configurations

	Display Configuration			
Display	A	B	C	D
Aircraft	Track-Up	North-Up	Track-Up	North-Up
Navigation	North-Up	North-Up	North-Up	North-Up
Sensor	Sensor-View	North-Up	Sensor-View	North-Up
Mission	North-Up			
# Reference Frames	3	1	3	1
Orientation Aid	Yes	Yes	Yes	Yes
Integrated	No	No	Yes	Yes

**Integration Effect:
A vs. C and B vs. D**

**Reference Frame Alignment
Effect:
A vs. B and C vs. D**

Aircraft Simulator

File Edit View Insert Tools Desktop Window Help

Sensor pt North Up Stop Subject Run# 0.1

LJS RJS Integ 2D Bnk Twist Squint PFD Course Ind

Trigger Light

Direction Switch

Reset Switches

282 Heading

TRAINING ONLY

Car approaching intersection FROM the WEST

Aircraft Simulator

File Edit View Insert Tools Desktop Window Help

Sensor pt North Up Stop Subject Run# 0.1

LJS RJS Integ 2D Bnk Twist Squint PFD Course Ind

ALIGNED

Trigger Light

Direction Switch

Reset Switches

282 Heading

TRAINING ONLY

Car approaching intersection FROM the NORTH

Aircraft Simulator

File Edit View Insert Tools Desktop Window Help

Sensor pt North Up Stop Subject Run# 0.1

LJS RJS Integ 2D Bnk Twist Squint PFD Course Ind

Trigger Light

Direction Switch

Reset Switches

INTEGRATED

TRAINING ONLY

Car approaching intersection FROM the EAST

Aircraft Simulator

File Edit View Insert Tools Desktop Window Help

Sensor pt North Up Stop Subject Run# 0.1

LJS RJS Integ 2D Bnk Twist Squint PFD Course Ind

Trigger Light

Direction Switch

Reset Switches

TRAINING ONLY

Car approaching intersection FROM the NORTH

Current Study Results

■ Data quantity

- 16 Subjects
- 2.5 hours per subject
- Nov - Dec 2015

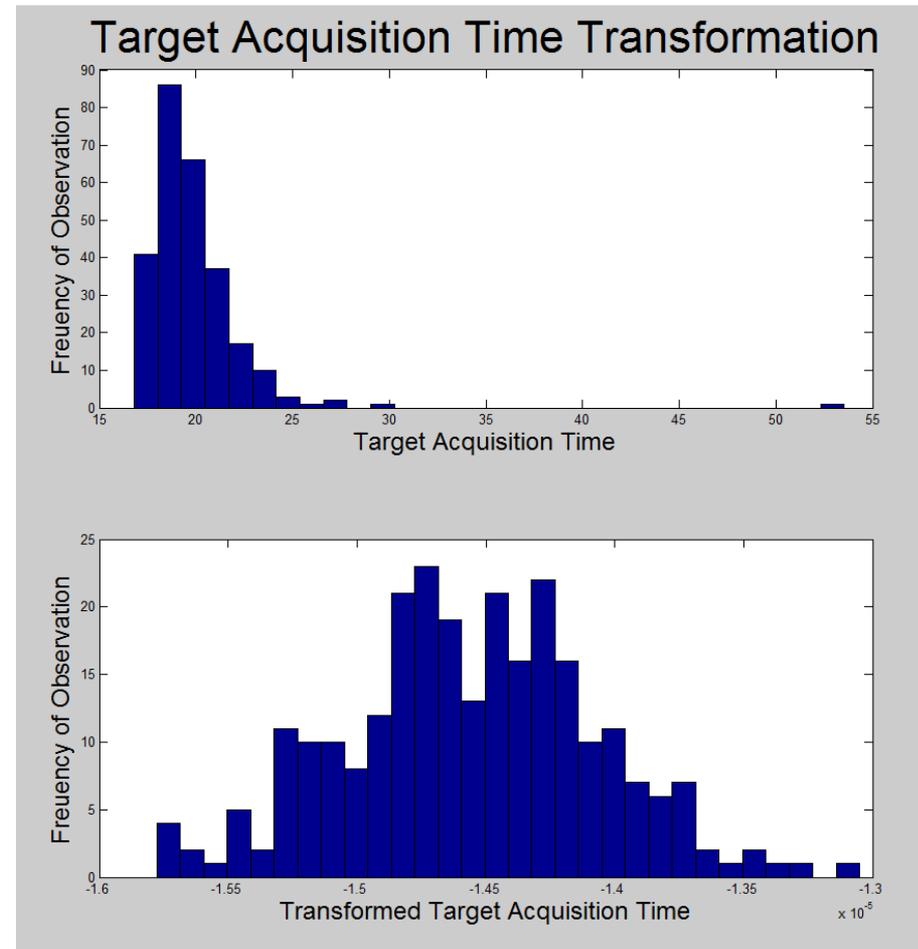
■ Dependent Variables

- Performance
 - ✓ Orientation Time
 - ✓ Target Acquisition Time
 - ✓ Combined Track Error
- Workload
 - ✓ Bedford Scale (Subjective)
 - ✓ Reaction Time (Secondary)

■ Independent Variables

- Display Configuration
 - ✓ Reference Frame Alignment
 - ✓ Display Integration
- Subject
- Image Rotation Angle
- Subject Trial Number
- Target
- Target Movement

- Box-Cox Transformation to Normalize Data [16]



$$TAT' = \frac{(TAT^{-3.9279} - 1)}{-3.9279}$$

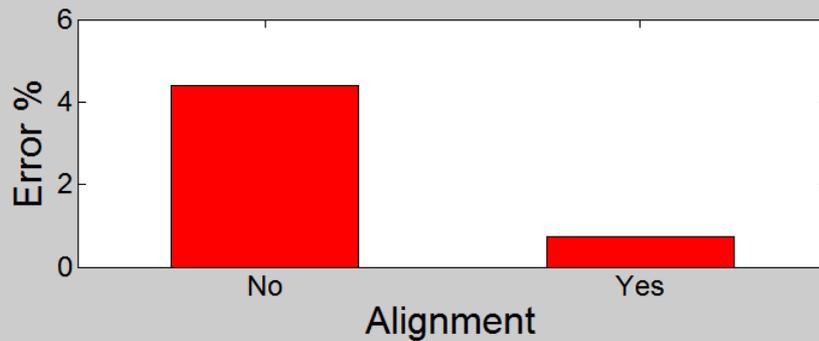
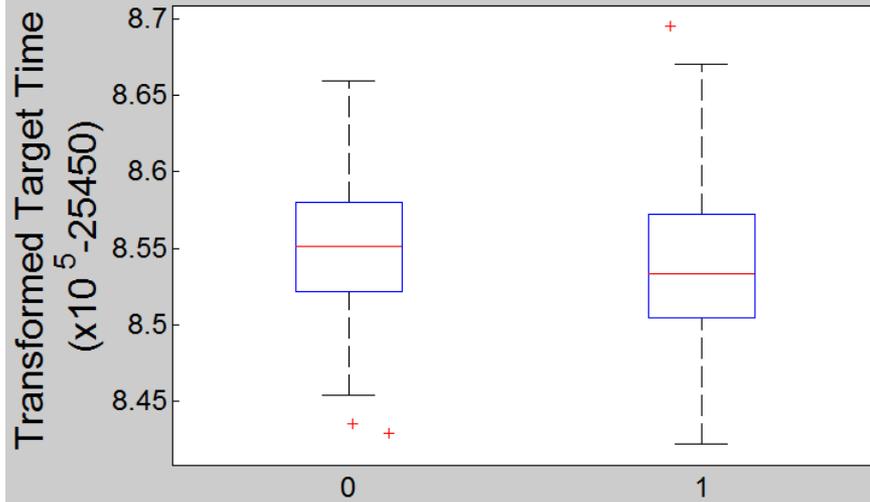


Linear Regression Model

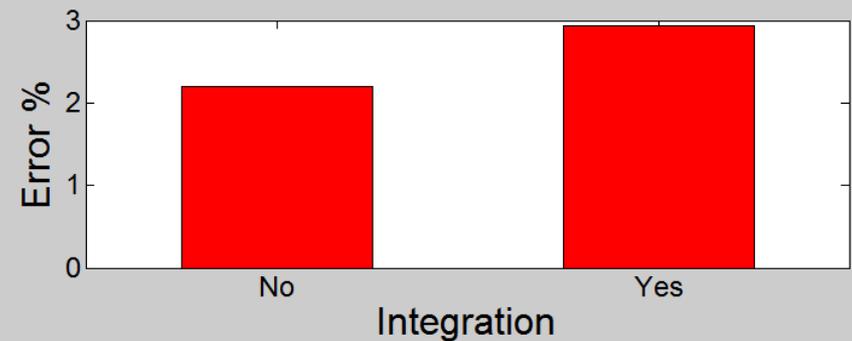
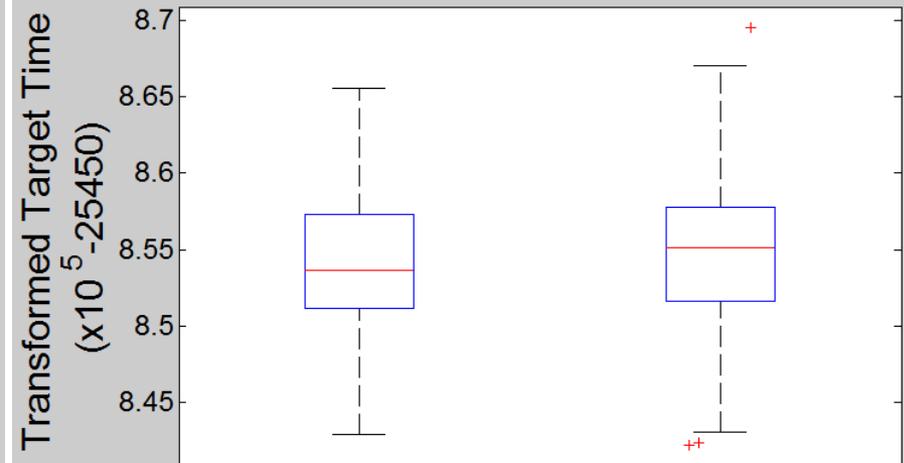
Multi-Factor Linear Regression	Orientation Time	Tgt Acq Time	Comments
Reference Frame Alignment	F(503), p(2.86e-102)	F(14.7), p(1.60e-4)	Hypothesis: Alignment will affect human performance
Display Integration	Not significant	Not significant	Hypothesis: Display Integration will affect human performance
Subject	F(152), p(0)	F(13.5), p(1.38e-24)	Pairwise within subjects
Image Rotation Angle	Not significant	Not significant	Contrary to literature
Subject Trial #	F(7.58), p(5.93e-3)	F(9.13), p(2.78e-3)	Counterbalanced
Target	Not significant	F(39.1), p(1.09e-20)	Counterbalanced
Target Movement	F(52.8), p(4.73e-13)	n/a	Secondary Hypothesis
Alignment*Subject	F(4.63), p(7.62e-9)	Not significant	
Subject* Subject Trial #	F(2.43), p(0.00163)	Not significant	

Results Summary: Target Acquisition Time

Target Acquisition Time vs. Alignment

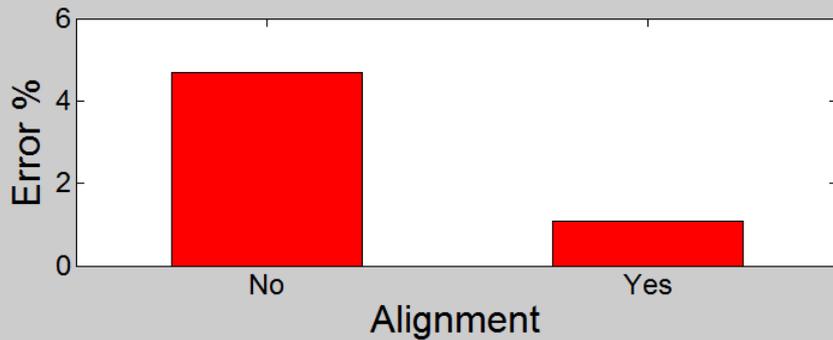
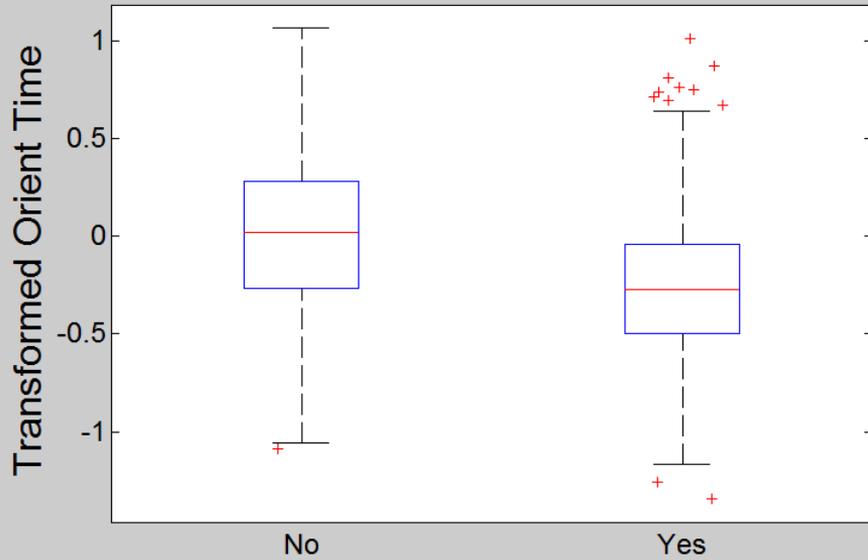


Target Acquisition Time vs. Integration

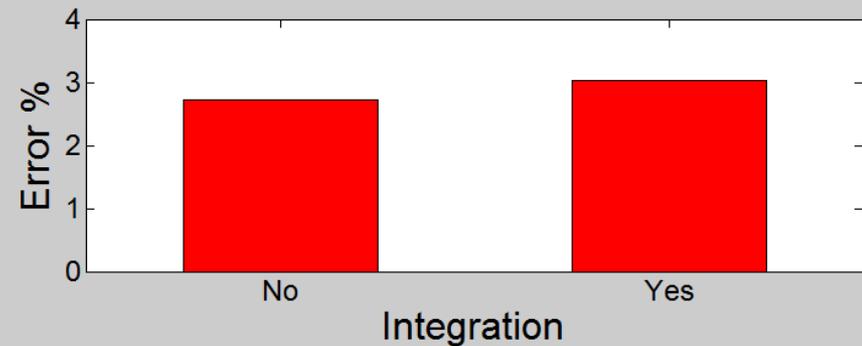
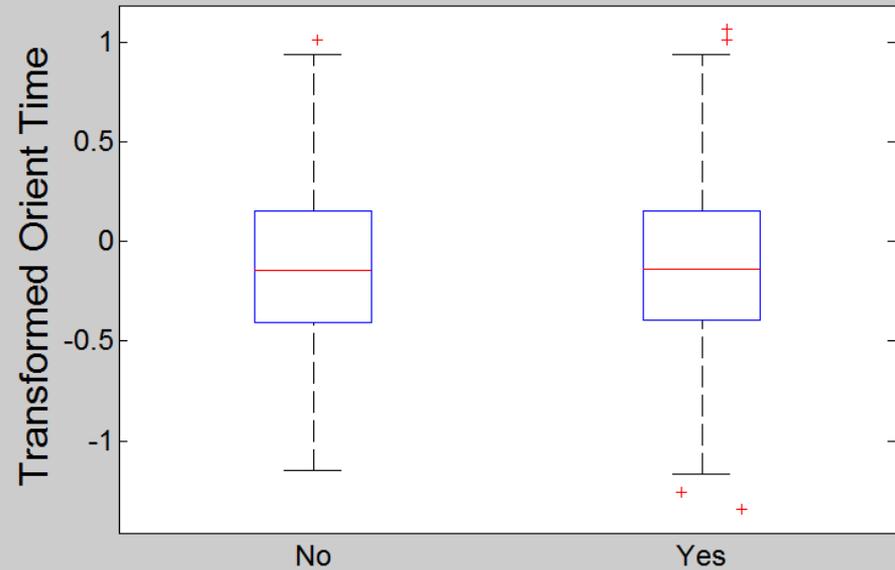


Results Summary: Orientation Time

Orient Time vs. Alignment



Orient Time vs. Integration



Subjective Observations

Subjective

Display Rankings

1 is best, 4 is worst

4	
3	
5	
1	

Disp. A Separate Misaligned	Disp. B Separate Aligned	Disp. C Integrated Misaligned	Disp. D Integrated Aligned
2	1	4	3
3	1	4	2
3	1	4	2
3	1	4	2
1	3	4	2
3/4	2	3/4	1
4	3	2	1
4	3	2	1
4	2	3	1
3	1	4	2
4	3	2	1
3	2	4	1
4	2	3	1
4	3	2	1
4	3	2	1
2	1	4	3

Pairwise Comparisons

16 subjects 2-sided student t-test $t_{crit} = 3.208$ (Bonferroni for 6) $\alpha_B = 0.0083$ ($\alpha = 0.05$) 1-sided p-value			Reference Frame Alignment		Display Integration		Interaction Effects	
			Sep. A \neq B	Integr. C \neq D	misAlign A \neq C	Aligned B \neq D	Conflict C \neq B	Combine A \neq D
Performance ²	Orientation Time ¹	t*	8.63	10.8	-1.24	0.423	8.22	10.0
		p-value	1.67e-7	8.50e-9	0.883	0.339	3.07e-7	2.50e-8
	Target Acquisition Time ¹	t*	1.66	4.26	-2.50	0.504	3.02	1.68
		p-value	0.0593	3.40e-4	0.988	0.311	4.29e-3	0.0570
	Combined Track Error ¹	t*	-0.015	-0.292	0.215	-0.0743	-0.286	-0.0931
		p-value	0.506	0.613	0.416	0.529	0.611	0.536
Workload ²	Subjective Workload Rating	t*	-0.593	-0.273	-1.73	-1.96	1.80	-1.73
		p-value	0.719	0.606	0.948	0.965	0.0457	0.948
	Reaction Time ¹	t*	0.911	2.63	-4.25	-2.35	3.93	-1.61
		p-value	0.188	9.40e-3	0.9997	0.984	6.65e-4	0.936

¹Transformed variables

²For all dependent variables smaller numbers are desirable



Preliminary Conclusions

- **Reference Frame Alignment improved performance on orientation time and target acquisition time.**
- **Display Integration did not have a significant impact on performance.**
- **Display integration had a negative impact on workload with one significant measurement of secondary workload and other workload measurements trending towards significance.**
- **Display Integration was more effective with aligned displays.**



Discussion

- **Integrated Display Effect**
 - Changing crosscheck pattern
- **Aircraft Display (PFD)**
 - Subjects all stated they didn't use PFD
 - Complete reliance on flight path predictor
- **Control Errors**
 - Right-left bank errors when aircraft heading South on misaligned displays (tilting left to bank right)
 - Different control methods (tilt vs. twist) for left and right hands avoided confusion (limited observation ~ 2 subjects)
- **Future Work**
 - Examine aircraft display impact, given integrated flight path predictor information on navigation display
 - Continue to test reference frame alignment effect during increasingly realistic simulations
 - ✓ Squint angle
 - ✓ More complex navigation tasks
 - ✓ Datalink latency

Questions

