



Human Systems  
Integration Division



# *Cognitive Demands of Flying Technologically Advanced Aircraft*

**Barbara Burian, Ph.D., FRAeS**

NASA Ames Research Center

Integrated Intelligent Flight Deck Project Scientist



**IIFD**

Integrated Intelligent Flight Deck

# A Collaborative Effort

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Barbara Burian

Lynne Martin

Bonny Christopher

Capt. Randy Phillips (Ret.)



Office of Human Factors Research  
and Engineering

CAMI



Citation Mustang Program  
Wichita, KS



Citation Mustang Program  
Wichita, KS



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# Common Beliefs

## Advanced Technologies

Integrated Glass Cockpits,  
Highly Capable GPS/FMS  
Sophisticated Autoflight Systems  
Moving Maps  
FADEC  
On-board Weather, Terrain, and Traffic Displays\*  
Other Resources\* (e.g., Taxi Diagrams, Electronic Checklists)

\* Equipage varies

## Yield

## Improved Human Performance

Improved situational awareness  
Improved navigation and flight path precision  
Reduced fatigue  
Reduced workload  
Single-pilot operation capable

“These technologies make aircraft safer, easier to operate and more useful” J. Olcott, World Airline Training Symposium, 2007



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# Common Beliefs

Advanced  
Technologies

Integrated Glass Cockpits  
Highly Capable  
Technologies?

\* Equipage varies

**Absolutely!**

Impressive a

On-board Weather, Terrain, and Traffic Displays\*  
Other Resources\* (e.g., Taxi Diagrams, Electronic Checklists)

Yield

Improved Human  
Performance

Improved situational awareness  
Improved navigation  
easier to operate?

**Yes.....and No**

Improved human performance  
pilot operation capable

**“These technologies make aircraft safer, easier to operate and more useful”**

J. Olcott, World Airline Training Symposium, 2007



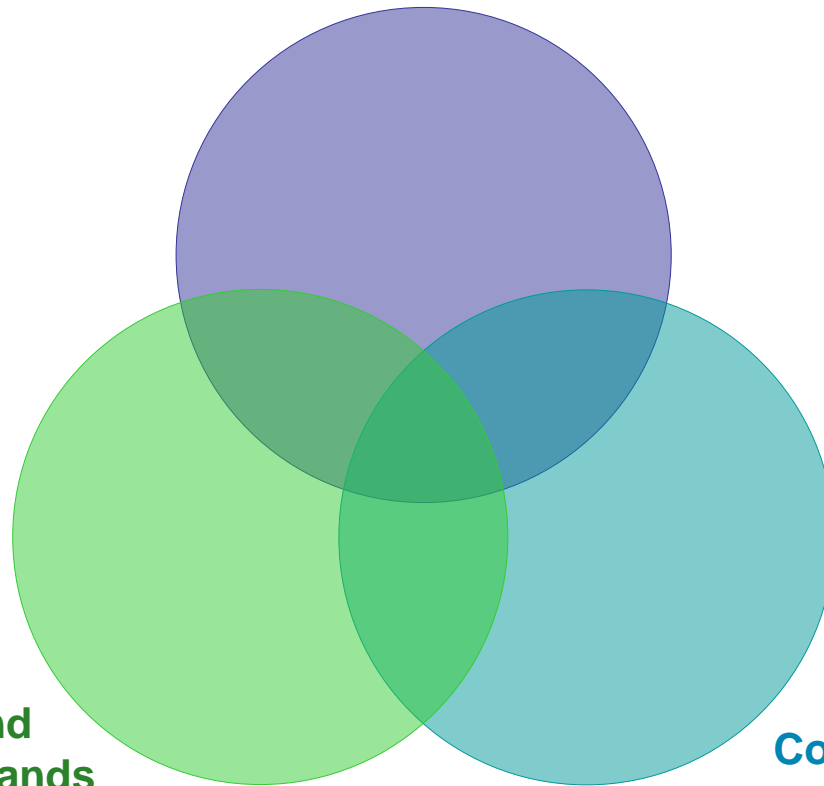
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# *Intersections of and Relationships Among:*

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**Operational Demands**



**Technology and  
Automation Demands**

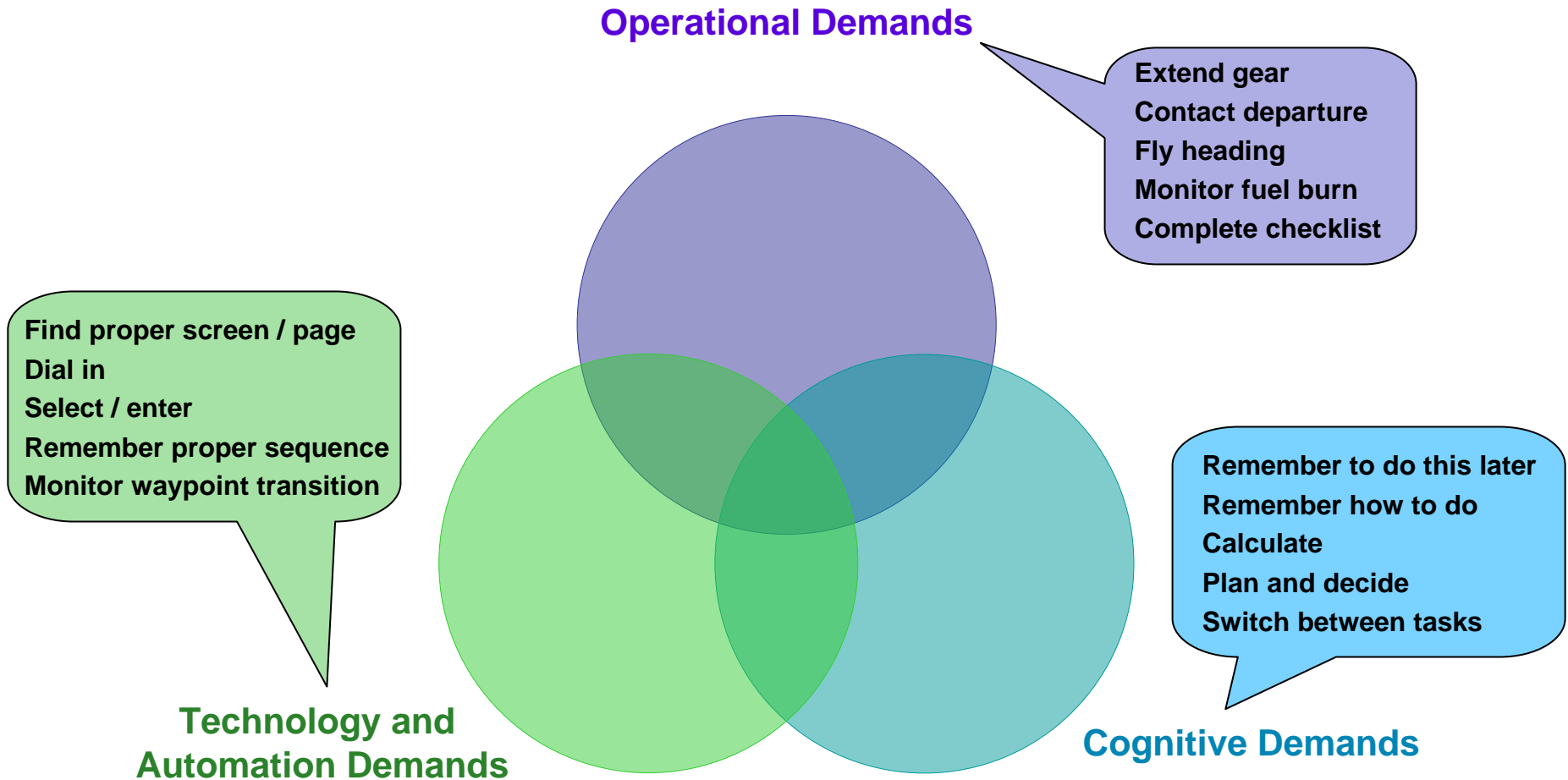
**Cognitive Demands**



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# Intersections of and Relationships Among:

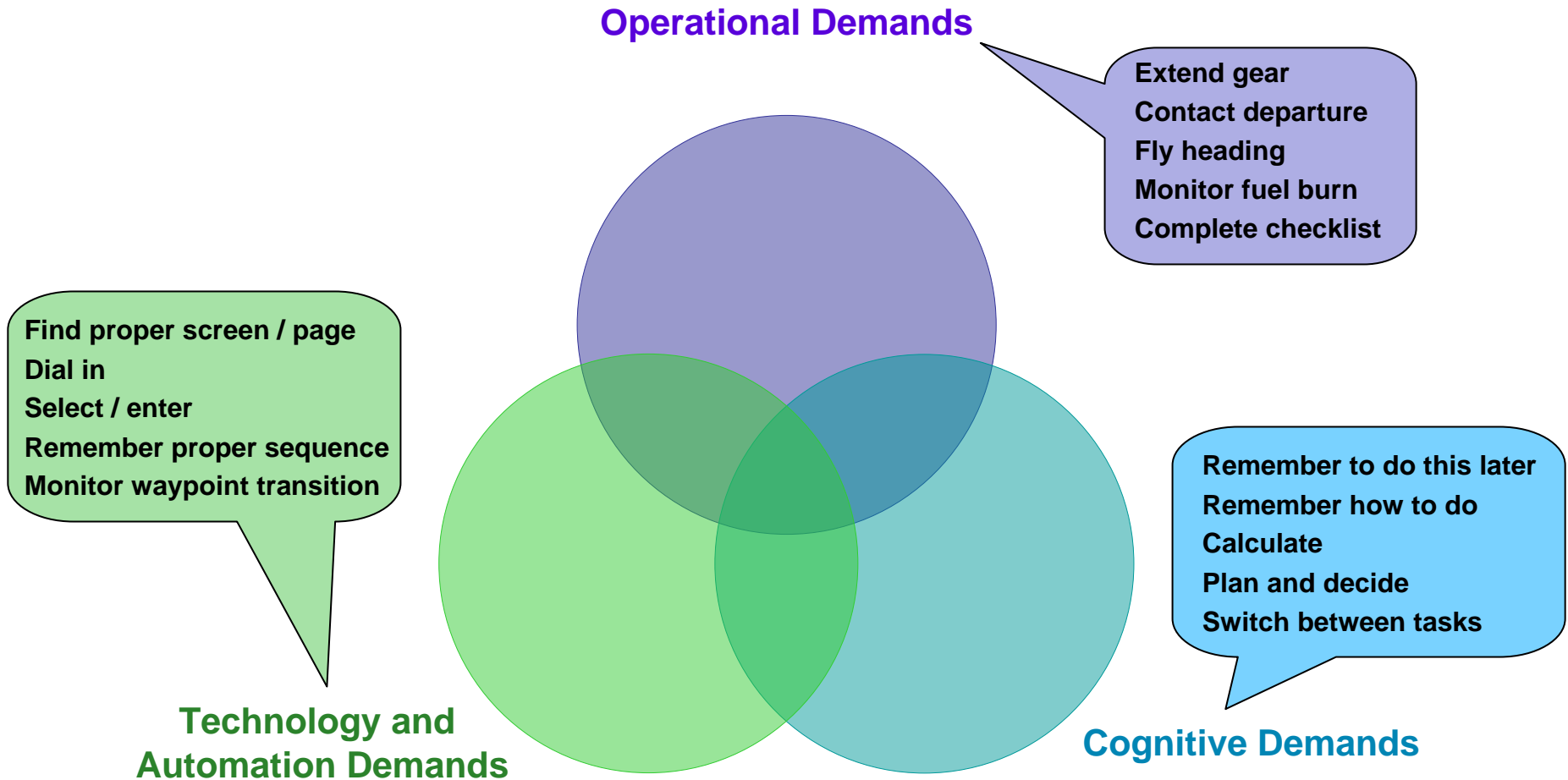


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# Intersections of and Relationships Among:

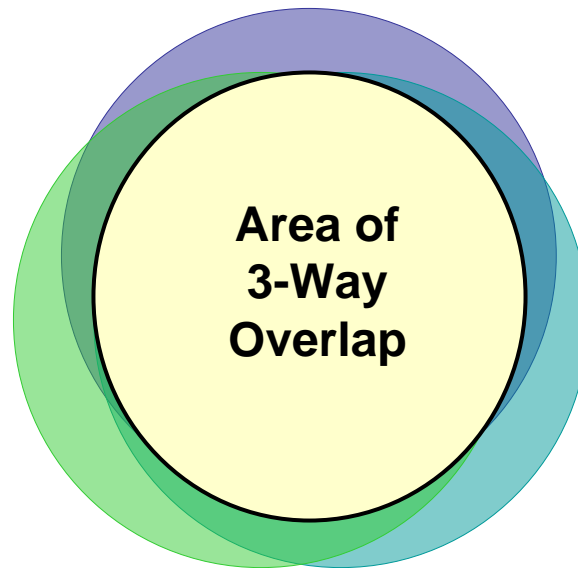


To assist with **Operational Demands**, **Technology and Automation** create **Cognitive Demands**

# *Intersections of and Relationships Among:*

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**Operational Demands**



**Technology and  
Automation Demands**

**Cognitive Demands**



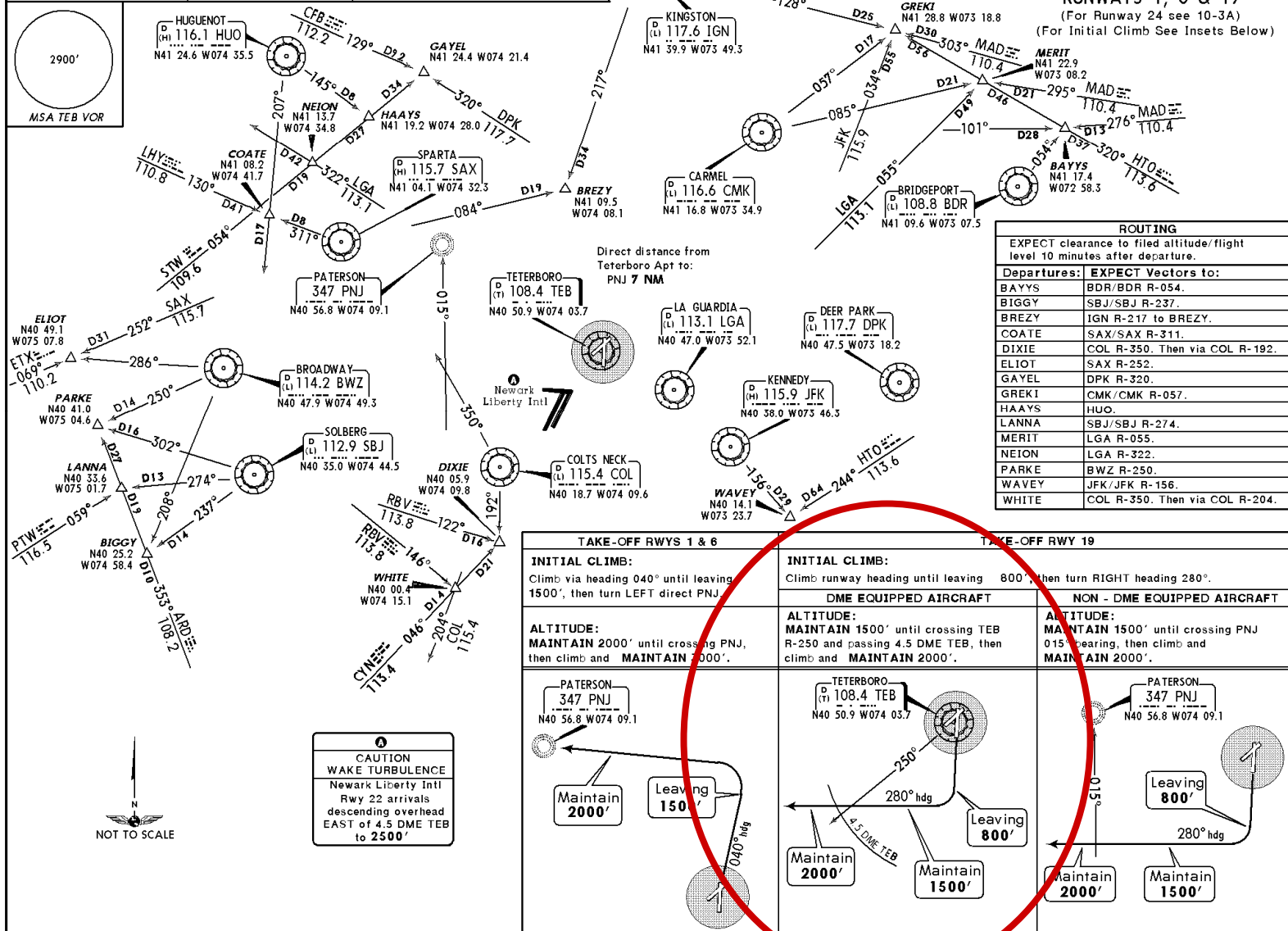
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# TETERBORO FIVE DEPARTURE

KTEB/TEB  
 TETERBORO

NEW YORK Departure (R)  
**119.2 126.7**  
 Apt Elev 9'  
 Trans level: FL180 Trans alt: 18000'



**TETERBORO FIVE DEPARTURE**  
 RUNWAYS 1, 6 & 19  
 (For Runway 24 see 10-3A)  
 (For Initial Climb See Insets Below)

ROUTING	
EXPECT clearance to filed altitude/flight level 10 minutes after departure.	
Departures:	EXPECT Vectors to:
BAYBYS	BDR/BDR R-054.
BIGGY	SBJ/SBJ R-237.
BREZY	IGN R-217 to BREZY.
COATE	SAX/SAX R-311.
DIXIE	COL R-350. Then via COL R-192.
ELIOT	SAX R-252.
GAYLE	DPK R-320.
GREKI	CMK/CMK R-057.
HAAYS	HUO.
LANNA	SBJ/SBJ R-274.
MERIT	LGA R-055.
NEION	LGA R-322.
PARKE	BWZ R-250.
WAVEY	JFK/JFK R-156.
WHITE	COL R-350. Then via COL R-204.

TAKE-OFF RWYS 1 & 6	TAKE-OFF RWY 19	
<b>INITIAL CLIMB:</b> Climb via heading 040° until leaving 1500', then turn LEFT direct PNJ.	<b>INITIAL CLIMB:</b> Climb runway heading until leaving 800', then turn RIGHT heading 280°.	
<b>ALTITUDE:</b> MAINTAIN 2000' until crossing PNJ, then climb and MAINTAIN 2000'.	<b>DME EQUIPPED AIRCRAFT</b>	<b>NON - DME EQUIPPED AIRCRAFT</b>
	<b>ALTITUDE:</b> MAINTAIN 1500' until crossing TEB R-250 and passing 4.5 DME TEB, then climb and MAINTAIN 2000'.	<b>ALTITUDE:</b> MAINTAIN 1500' until crossing PNJ 015 bearing, then climb and MAINTAIN 2000'.

**CAUTION WAKE TURBULENCE**  
 Newark Liberty Intl  
 Rwy 22 arrivals descending overhead EAST of 4.5 DME TEB to 2500'



KTEB/TEB  
 TETERBORO

JEPPESEN TETERBORO, NJ  
 27 JUL 07 10-3 SID

# TETERBORO FIVE DEPARTURE

## TAKE-OFF RWY 19

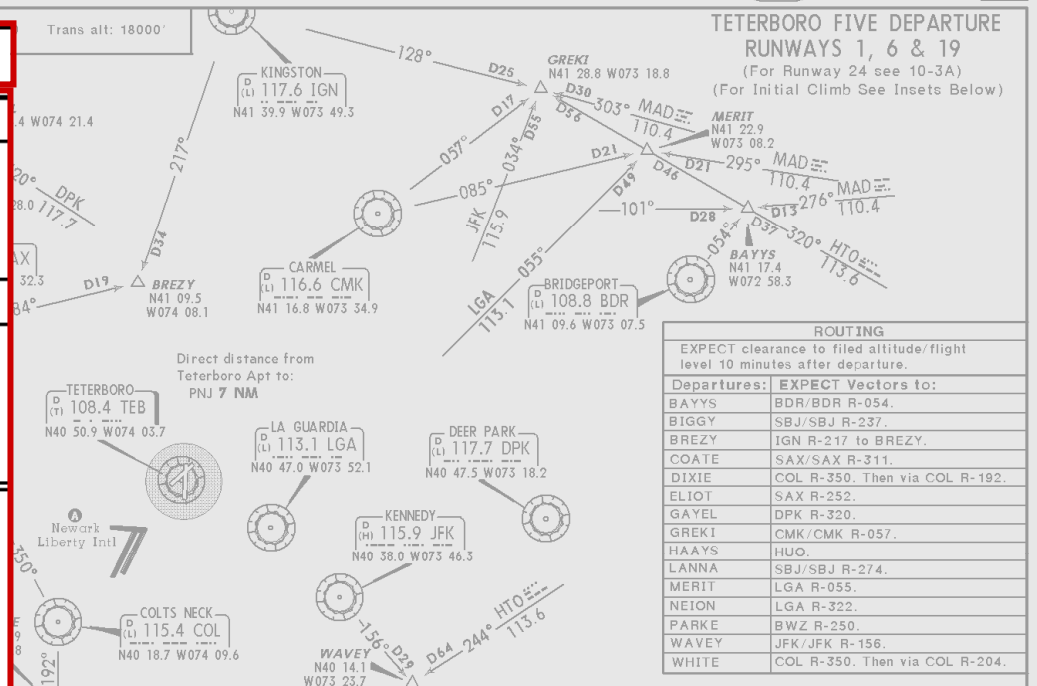
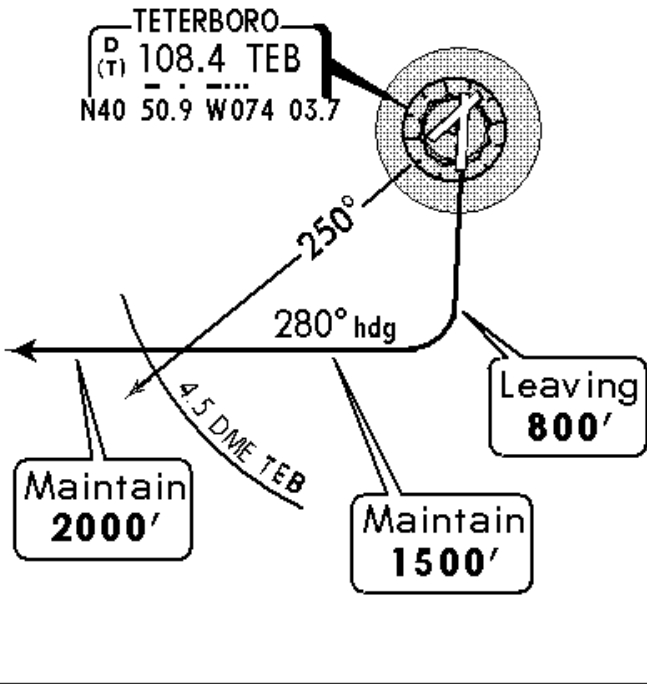
### INITIAL CLIMB:

Climb runway heading until leaving 800', then turn RIGHT heading 280°.

### DME EQUIPPED AIRCRAFT

### ALTITUDE:

MAINTAIN 1500' until crossing TEB R-250 and passing 4.5 DME TEB, then climb and MAINTAIN 2000'.



TAKE-OFF RWYS 1 & 6		TAKE-OFF RWY 19	
<b>INITIAL CLIMB:</b> Climb via heading 040° until leaving 1500', then turn LEFT direct PNJ.		<b>INITIAL CLIMB:</b> Climb runway heading until leaving 800', then turn RIGHT heading 280°.	
<b>DME EQUIPPED AIRCRAFT</b>		<b>NON - DME EQUIPPED AIRCRAFT</b>	
<b>ALTITUDE:</b> MAINTAIN 2000' until crossing PNJ, then climb and MAINTAIN 3000'.		<b>ALTITUDE:</b> MAINTAIN 1500' until crossing TEB R-250 and passing 4.5 DME TEB, then climb and MAINTAIN 2000'.	

KTEB/TEB  
TETERBORO

## TETERBORO FIVE DEPARTURE

### TAKE-OFF RWY 19

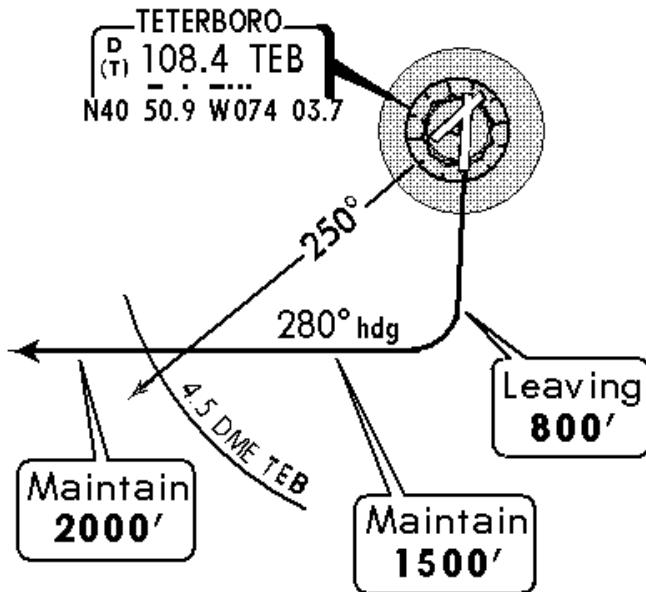
#### INITIAL CLIMB:

Climb runway heading until leaving 800',  
then turn RIGHT heading 280°.

#### DME EQUIPPED AIRCRAFT

#### ALTITUDE:

**MAINTAIN 1500'** until crossing TEB  
R-250 and passing 4.5 DME TEB, then  
climb and **MAINTAIN 2000'**.



## Operational Task Demands

- receive clearance to take-off from Tower
- throttles to TO setting
- take off, maintain tracking along center line
- positive rate of climb – gear up
- 400' agl with adequate airspeed – flaps up
- around 400' agl – throttles reduced to MCT
- around 800' agl – ATC handoff to Departure
- 800' agl – turn to 280° heading
- contact Departure
- 1000' agl – engage autopilot and yaw damper
- continue climbing to 1500' agl
- 1500' agl – level off
- cross 250° radial
- cross 4.5 DME from TEB
- climb to 2000' agl
- 2000' agl – level off

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands



Cognitive Demands

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

receive clearance to take-off from Tower  
throttles to TO setting  
take off, maintain tracking along center line

SA and Attention

## Situation Awareness (SA) and Attention –

Keeping track of what is going on (seeing cues in the environment, understanding where they came from, understanding what they mean about your current situation, being able to predict what will happen in the future based on those cues)

Cognitive Demands

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

receive clearance to take-off from Tower  
throttles to TO setting  
take off, maintain tracking along center line  
positive rate of climb – gear up

SA and Attention

SA and Attention  
Prospective Memory

## Dealing with Interruptions and Distractions

### Prospective Memory –

Remembering to perform a task later (form an intention, identify cues when task should be performed in future, see cues, remember delayed intention, complete task)

Cognitive Demands



# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

receive clearance to take-off from Tower  
throttles to TO setting  
take off, maintain tracking along center line  
positive rate of climb – gear up  
400' agl with adequate airspeed – flaps up  
around 400' agl – throttles reduced to MCT

## Concurrent Tasks –

Trying to complete two or more tasks at the same time, typically involves interleaving the tasks

SA and Attention

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

Cognitive Demands

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

receive clearance to take-off from Tower  
throttles to TO setting  
take off, maintain tracking along center line  
positive rate of climb – gear up  
400' agl with adequate airspeed – flaps up  
around 400' agl – throttles reduced to MCT

## Concurrent Tasks –

Trying to complete two or more tasks at the same time, typically involves interleaving the tasks

SA and Attention

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

## Cognitive Cost of Concurrent Tasks:

- remembering to interleave tasks
- remembering where you left off and associated start-up time getting back into a task

Cognitive Demands

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

receive clearance to take-off from Tower  
throttles to TO setting  
take off, maintain tracking along center line  
positive rate of climb – gear up  
400' agl with adequate airspeed – flaps up  
around 400' agl – throttles reduced to MCT  
800' agl – turn to 280o heading  
around 800' agl – ATC handoff to Departure  
contact Departure

SA and Attention

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

Working memory

## Working Memory –

Active mental processing (holding and integrating information in your mind in real time, often requires rehearsal to keep information in working memory, capacity is limited)

Cognitive Demands

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

← Set-up automation

receive clearance to take-off from Tower  
throttles to TO setting  
take off, maintain tracking along center line

positive rate of climb – gear up  
400' agl with adequate airspeed – flaps up  
around 400' agl – throttles reduced to MCT

800' agl – turn to 280° heading  
around 800' agl – ATC handoff to Departure  
contact Departure

around 1000' agl – engage autopilot and yaw damper  
continue climbing to 1500' agl

1500' agl – level off  
cross 2500 radial  
cross 4.5 DME from TEB  
reset ALT window to 2000' agl  
climb to 2000' agl

2000' agl – level off

SA and Attention

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

Working memory

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory  
Monitor

SA and Attention

SA and Attention  
Prospective Memory  
SA and Attention

SA and Attention  
Prospective Memory  
Monitor

Cognitive Demands

# TETERBORO FIVE DEPARTURE

Runway 19

Operational Demands

All within about two minutes!

SA and Attention

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory

Working memory

SA and Attention  
Prospective Memory

SA and Attention  
Prospective Memory  
Monitor

SA and Attention

SA and Attention  
Prospective Memory  
SA and Attention

SA and Attention  
Prospective Memory  
Monitor

Cognitive Demands

Monitoring radio

Monitoring aircraft performance

Adjust Trim

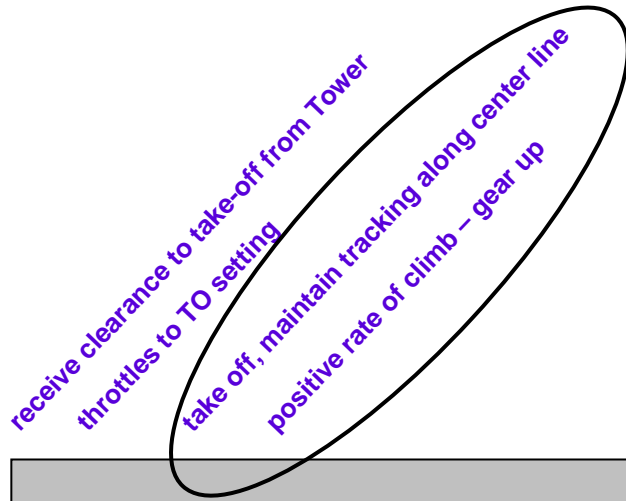
Monitoring automation performance

Looking for traffic

Other issues (weather, other radio calls, alerts, etc.)

\*\* All tasks take time\*\*

# A Closer Look at Task Demands



SA and Attention

SA and Attention  
Prospective Memory

## Takeoff, maintain tracking along center line

Raise nose to match flight director bars on PFD

Monitor increase of speed to V2

Adjust for crosswind or gusts as needed to track center line

## Positive rate of climb, gear up

Monitor rate of climb

Determine positive rate

Remember to raise gear

Push gear lever up

Listen for gear retraction

Watch for panel lights to extinguish

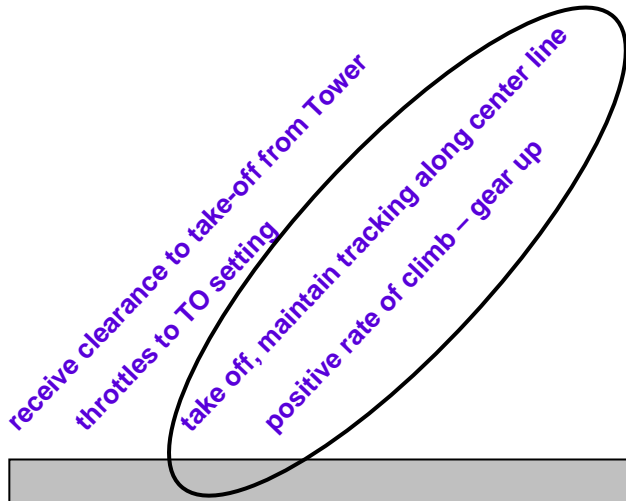


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# A Closer Look at Task Demands



Takeoff, maintain tracking along center line

Raise nose to match flight director bars on PFD

Monitor increase of speed to V2

Adjust for crosswind or gusts as needed to track center line

Positive rate of climb, gear up

Monitor rate of climb

2007 VLJ Study (reports from July 2005-June 2006):

- 170 ASRS incident reports, 218 NTSB accident reports
- 24 out of first 50 ASRS reports – TEB
- 16 out of those 50 – overshooting 1500' agl on TEB 5 departure off Rwy 24 (very similar procedures as for Rwy 19)



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# Setting the PFD Backlighting on the G1000



1. Press the MENU button on PFD
2. Push the FMS knob
3. Scroll with the large FMS knob to the first field
4. Use the small FMS knob to select PFD DSPL from a list
5. Scroll with the large FMS knob to the next field
6. Use the small FMS knob to select MANUAL
7. Press the ENT button
8. Use the small FMS knob to set the intensity percentage desired
9. Press the ENT button

This procedure **does not** change the backlighting of the PFD soft keys at the same time

This procedure **cannot** be performed from the MFD unless the Display Backup button is pressed first



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# More on Advanced Technology Demands

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## Advanced Technologies and Automation:

- Increase amount of set-up time (read, understand, enter)
- Reduce flying / navigation tasks once set-up
- Increase monitoring and “system manager” tasks
- Some tasks that could once be done in parallel now must be done sequentially
  - e.g., “Aircraft 1234, turn right heading 210, contact departure on 129.75”
  - Increases decision making – which will you do first?
  - Increases amount of time before second action is initiated
- Increase situation awareness and facilitate planning and decision making (potentially)
- Can be used to off-load workload during most types of emergencies
- Increase training requirements and amount of information that must be stored in long-term memory – currency is an issue



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# *CODA – Cognitive and Operational Demands Analysis*

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- Number of steps required for task completion
- Time for step/task completion
- Sensory channel input/output (visual, auditory, speech, motor, etc.)
- Major cognitive demands/process
  - working memory
  - prospective memory (remembering to do something at a later time – delayed intention)
  - attention/situation awareness
  - divided attention and shifting mental sets
  - decision making
  - planning, etc.
- “Using the display” demands (softkey, dedicated button, single menu, multiple menus, etc.)
- Recall vs. Recognition
- Cues and Strategies
- Display interface differences/issues

# *CODA – Cognitive and Operational Demands Analysis*

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- Other operational demands
  - ATC expects timely response
  - Must plan route to avoid weather
  - Re-programming required
  - Limited time available for programming task completion
  - Must divide attention between out-the-window and in-the-cockpit
  - Must manage concurrent tasks
  - Must complete some tasks in sequence, some tasks in parallel
  - Must deal with interruptions, etc.
- Number, type, and location of resources required (MFD, paper CL, etc.)
- Common errors (procedures, interface, etc.)
- Workload Assessment

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**Barbara.K.Burian@nasa.gov**

**<http://human-factors.arc.nasa.gov/eas>**

**Flight Cognition Laboratory**

**<http://human-factors.arc.nasa.gov/ihs/flightcognition/>**



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