PSYC305

Applied Cognition & Neuroscience

Aviation & Aerospace

Aviation & Aerospace

Aviation has been a significant area for Applied Cognitive Psychology since 1939

Research demand came from "bottom up" human performance couldn't keep up with advances in aircraft capabilities

Researchers conducted experiments on shape coding of aircraft controls
Led to standardisation of the shape and location of controls

Aircraft displays could also be very confusing

Increasing numbers of planes in the air and the introduction of radar led to new air traffic control problems

With the advent of long flight distances and high speed jets things began to get really interesting…

ME262

"The Biology Barrier"

The conditions in aircraft cockpits have significant effects on human performance (and cognitive processes)

Fatigue – demanding task, sustained flight times, jet lag
Vibration – Tracking and reaction time performance
Acceleration – "G" forces & G-LOC

Later: Cognitive limits

Mental workload – information overload & time stress
Situation awareness – spatial disorientation & finding the picture

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Aircrews were flying longer and more frequently

The flight tasks became more demanding

Long flights coupled with changes in local time resulted in jet lag

Psychological Fatigue

"Psychological fatigue is defined as a subjectively experienced disinclination to continue performing the task at hand. It generally impairs human efficiency when individuals continue working after they have become aware of their fatigue" (Brown)

Psychological Fatigue

The main effect of psychological fatigue is a ***progressive involuntary withdrawal*** of attention from task demands.

1. Switching attention to inner thoughts
2. Empty Field Myopia – Visual fixation moves closer & closer
3. Microsleeps & nodding off

Self-ratings of fatigue don't always correlate well with error rates (affects proceduralised behaviour first)

Fatigue produces performance decrements long before you are aware of it!

Psychological Fatigue

Causes of fatigue:

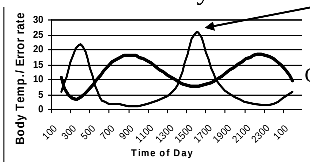
Too little sleep (more than time on task)
Boredom (too little stimulation)
Prolonged stress (too much stimulation)
Time of day (shift work)

During 37 hr missions basic flight skills degrade 40%

8% of all Class A flight mishaps due to fatigue

Circadian rhythms

peak time for aviation mishaps



Can be detected by core body temperature
Cycle reset by external cues (noise, meals UV light)
Isolation studies conducted to determine "natural" rhythm (24 or 28 hr clock?)

Psychological Fatigue

You <u>can</u> marshal your cognitive resources for brief periods

But switching attention back to task takes time *(up to 2-3 mins)*

Fatigue Counter-measures:

Sleep – work/rest schedules
Stimulants – caffeine, dexedrine
Reset clock – melatonin, & UV light

Whole-body Vibration

Continuous whole-body vibration (low frequency) can reduce tracking proficiency up to 40% (after only 1 hr)

Tracking is a measure of eye-hand coordination

Periodic whole-body vibration is not as bad, but after 4 hrs exposure reaction times can be four times longer

Vibration effects persist up to 30 mins after vibration ends

Acceleration Effects

Acceleration produces "G" force & a series of cognitive symptoms

"grey-out" ⟹ tunnel vision ⟹ "black-out" ⟹ G-induced loss of consciousness (G-LOC)

Cranial blood pressure is reduced to zero as blood pools in torso

Fighter pilots use "G-suits", conformal seats, and straining manoeuvre to increase tolerance

Cognitive limits

Mental workload – information overload & time stress

Situation awareness – spatial disorientation & finding the picture

Mental Workload

(aka Cognitive Workload)

Proportion of available cognitive resources actively engaged

Subjective state

Overload possible due to capacity limits on attention and working memory

Issue arose from reports of test pilots
(cognitive theory development followed)

Why is mental workload an issue for pilots?

A brief history of aviation displays & controls

Mechanical Display Era

Dials and gauges added as they became available
no standardisation of display or control layouts

1917 – Bank & turn indicator
invented by Elmer Sperry

1927 first transatlantic solo flight by Charles Lindberg

1929 first instrument-only flight, James Doolittle

Electro-mechanical Display Era

By late 1950s standardised set of Primary Flight Displays

1. Airspeed 2. Attitude (pitch & bank) 3. Altimeter (vertical velocity)
4. Turn coordinator 5. Heading (turn rate) 6. Acceleration/thrust

Mental overload

Example: USAF F-15 Eagle
75 displays, 300 switches

Proliferation of displays and controls in aircraft cockpits led to task saturation & information overload

1978 -- Electro-optical display era

Simplified cockpit displays

F/A-18 Hornet
Multiple roles required multi-functional displays
two multi-function CRTs (DDIs)
with selectable display modes

and a head-up display (HUD)

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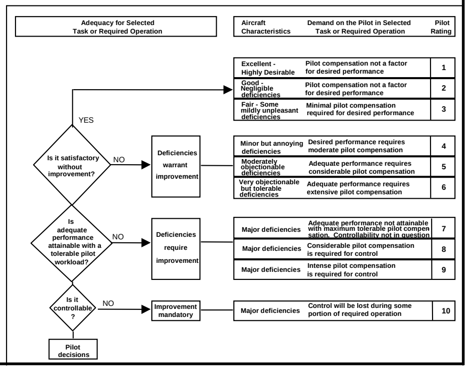
(cognitive theory development followed)

Chuck Yeager
1947 broke "sound barrier"
1952 1st to reach Mach II
1963 1st to eject at Mach II

Mental Workload

Subjective state – typically measured with subjective metrics

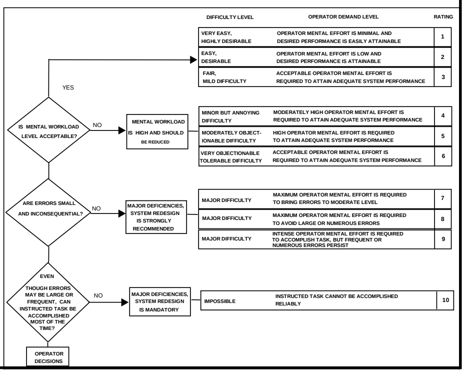
The Cooper-Harper aircraft handling characteristics scale
(Cooper & Harper, 1969)



Mental Workload

Subjective state – typically measured with subjective metrics

The Modified Cooper-Harper (MCH) workload rating scale
(Wierwille & Casalli, 1983)



Mental Workload

Subjective state – typically measured with subjective metrics

Subjective Workload Assessment Technique (SWAT)

(Developed by AAMRL: Reid, Shingledecker, Nygren & Eggemeier, 1981)

Multi-dimensional index of time load, mental effort, and stress.

Widely used because it can be used in cockpit with pilots verbally reporting scales

Thurstonian scaling technique
Involves preparation & pre-training (card sorting) to tailor scale

"Red line" of 40 points

SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE

NAME	DATE AND TIME

TASK BEING RATED

(MARK AN X IN ONE CHOICE FOR EACH OF THE THREE AREAS BELOW THAT BEST DESCRIBES WHAT YOU BELIEVE THE TASK WORKLOAD TO BE.)

I. TIME LOAD

1 Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

2 Occasionally have spare time. Interruptions or overlap among activities occur frequently.

3 Almost never have spare time. Interruptions or overlap among activities are frequent, or occur all the time.

II. MENTAL EFFORT

1 Very little conscious mental effort or concentration required. Activity is almost automatic requiring little or no attention.

2 Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3 Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

III. PSYCHOLOGICAL STRESS

1 Little confusion, frustration or anxiety exists and can be easily accomodated.

2 Moderate stress due to confusion, frustration, or anxiety. Noticeably adds to workload. Significant compensation is required to maintain adequate performance.

3 High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Mental Workload

Subjective state – typically measured with subjective metrics

Task Loading Index (NASA-TLX)

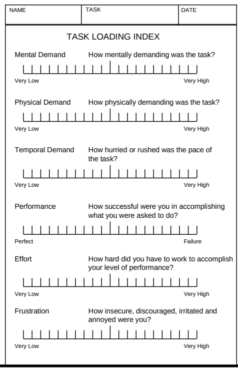
(Developed by NASA: Hart & Staveland, 1988)

Multi-dimensional index of rating components (typically 6 components).

Widely used in many domains

Can be used with or without post-hoc scaling procedures (RTLX)

No acknowledged "Red line"



Mental Workload

Subjective state – typically measured with subjective metrics

The AFFTC Revised Workload Estimate Scale

(Originally developed by AF-SAM, revised by AFFTC: Ames & George, 1993)

Global index of peak and average workload

Very simple to use

No acknowledged "Red line"

NAME	DATE AND TIME
WORKLOAD ESTIMATE *(Circle the number of the statement which best describes the MAXIMUM workload you experienced during the past work period. Put an X over the number of the statement which best describes the AVERAGE workload you experienced during the past work period.)*	
1	Nothing to do; No system demands.
2	Light activity; Minimum demands.
3	Moderate activity; Easily managed; Considerable spare time.
4	Busy; Challenging but manageable; Adequate time available.
5	Very busy; Demanding to manage; Barely enough time.
6	Extremely busy; Very difficult; Non-essential tasks postponed.
7	Overloaded; System unmanageable; Essential tasks undone; Unsafe.
COMMENTS	

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De Waard's workload model

(1996)

Yerkes-Dodson Law
(1908)

D = underload, low levels of arousal, motivation or fatigue?

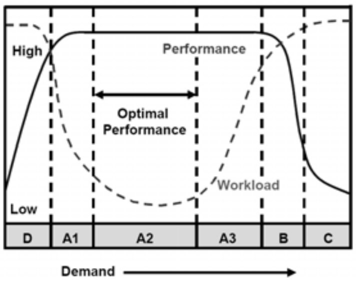
A1 = more effort invested, *resource limited*

A2 = medium demands, best performance, lowest workload

A3 = effort increased to meet increased demands, *data limited*

B = effort invested no longer enough to meet demand (or desire?)

C = overload, excessive levels of task demands



state-related effort

task-related effort

Mental Workload Measurement

Objective measures

Primary task (performance) measures

But can't always infer mental workload from performance: individual preferences and the Yerkes-Dodson Law

Secondary task (divided attention) measures

Secondary tasks can add workload or interfere with the primary task

Psychophysiological measures

Heart rate variability: increased variability = high workload
Eye blinks: fewer blinks = high workload
Electroencephalograph (EEG): P300 wave

Issues with instrumentation, individual differences in fitness & Yerkes-Dodson Law

Situation Awareness (SA)

If cognitive workload represents the proportion of available cognitive resources actively engaged, situation awareness can be thought of as the degree to which those resources are directed towards performing some task or accomplishing a specific goal

"*The perception of the elements of the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*" (Endsley, 1994).

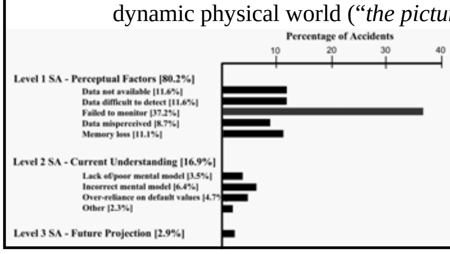
Three SA Levels: perception, comprehension, & projection

Situation Awareness (SA)

Debate whether SA is a process or a product

Like workload, SA construct came from operator reports (pilots & controllers)

Refers to a mental representation of the dynamic physical world ("*the picture*")



(Jones & Endsley, 1995)

SA Measurement

Situation Awareness Global Assessment Technique (SAGAT)
(Endsley 1990)

Please answer the questions about each aircraft by writing in the space provided or by circling an answer

Aircraft [1]: Speed – Under 100 knots
100-150 knots
150-200 knots
Over 200 knots
What is this aircraft's Altitude ______
Is this aircraft ascending/ descending/ level
Is this aircraft taking off/ landing/ overflight
.
.
.
Aircraft [n]: Speed – Under 100 knots
100-150 knots
150-200 knots
Over 200 knots
What is this aircraft's Altitude ______
Is this aircraft ascending/ descending/ level
Is this aircraft taking off/ landing/ overflight

Where will the next aircraft to enter your zone appear from?
Auckland airport
Whenuapai Airport
Ardmore Airport
Passed off from Centre

Will Aircraft [1] get to Ardmore before Aircraft [3] gets to Whenuapai airport? __________

Simulator-based "freeze frame" method

Confounded with memory limits & implicit processes

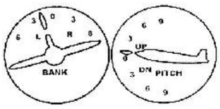
SA Measurement

The Situation Awareness Rating Technique (SART)
Divides SA into multidimensional construct like SWAT & TLX do for mental workload
(Selcon, Taylor, & Koritsas, 1991)

		Low						High
		1	2	3	4	5	6	7
DEMAND	Instability of Situation							
	Variability of Situation							
	Complexity of Situation							
SUPPLY	Arousal							
	Spare Mental Capacity							
	Concentration							
	Division of Attention							
UNDERSTANDING	Information Quantity							
	Information Quality							
	Familiarity							

SA & Primary Flight Displays

Attitude indicator (pitch & bank)



Split display
(outside in)

Combined display
(outside in)

Combined display
(inside out)

Pilot preference divided between outside in & inside out displays (depending on experience)

SA & Primary Flight Displays

Attitude indicator (pitch & bank)

All three displays indicate a bank to the right

Inside-out
horizon rotated counter-clockwise
(became aviation standard)

Outside-in
aircraft symbol rotated clockwise
(violates principle of pictorial realism)

Flight director
(frequency separated) aircraft symbol quickly rotated to reflect aileron inputs, horizon rotates more slowly

SA & Primary Flight Displays

Attitude indicator (pitch & bank)

All three displays indicate a bank to the right

Inside-out
horizon rotated counter-clockwise

Outside-in
aircraft symbol rotated clockwise

Strong tendency to control the part of the display that is moving & expect it to move in the same direction as the controls

Horizon control reversal (inside-out display)
Initial reaction for many pilots is to roll the horizon bar back to level which puts the plane into a steeper bank (a graveyard spiral)

SA & Primary Flight Displays

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All three displays indicate a bank to the right

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horizon rotated counter-clockwise
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Flight director
(frequency separated) aircraft symbol quickly rotated to reflect aileron inputs, horizon rotates more slowly

Faster & more accurate responses

Advanced Aircraft Flight Displays:
HUDs, NVGs, HMD, & PAs

Displays integrating more information & extending pilots' sensory capabilities

HUDs – Head-Up Displays first introduced as a gun sight
To improve pilot situation awareness (minimise "head-down" time) primary flight display information was added to the HUD

NVGs (Night vision goggles) & FLIR (forward-looking infrared) were introduced to extend flight operations into darkness

HMDs – Helmet-mounted displays, integration of digital, visual, situational, & real-time tactical information

PAs – Pilot's Associates, virtual reality displays, strategy & tactics, natural language interface

Advanced flight displays
Improving Situation Awareness

Head-up Display (HUD)

Improved SA, at a price!

Outside-in HUD displays (stationary horizon) can lead to problems due to mismatch with the view out the cockpit

Inside-out is easier to manage
problem of control reversal errors

Problems: Channelisation of attention & spatial disorientation

Advanced flight displays
Improving Situation Awareness

Night Vision Systems (NVG & FLIR)

Problems:

Narrow FOV & perspective distortions

Instrument blindness (NVG)

Channelised attention (FLIR)

Integrated Displays (PFDs)&
Helmet Mounted Displays (HMDs)

Advanced flight displays
Helmet Mounted Displays (HMDs)


Lite-Eye HMD
(for rotary wing aircraft only)


USAF Agile-Eye HMD
(still in development)


French Sextant Avionique Topsight
(for use with Rafale)

HMDs weigh 2.3 to 6.5 lbs (not always balanced)
at 2G = 4.6 to 13 lbs
at 8G = 18.1 to 52 lbs !!

HMDs FOV = 30 to 40 degrees, more head turning required = more fatigue

Mental workload & Situation awareness

Proliferation of displays and controls in aircraft cockpits led to task saturation & information overload

Evolution of Aircraft Display Design: Three Eras

Mechanical Era (WWI through 1950s)
idiosyncratic flightdeck layouts

Electro-Mechanical Era (Late 1950s to 1978)
cockpit displays standardised around Primary Flight Displays "T-line layout"

Electro-Optical Era (Late 1978 to present)
digital data & multi-function displays

There are problems on the ground too

Air Traffic Control (ATC)
Evolution of ATC

Spotters & Controllers communicate via telephone

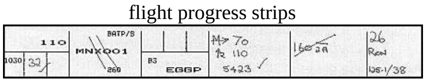
Radio, maps & "shrimp boats"

Increased air traffic required "mental model" of aircraft – flight progress strips

Addition of radar after WWII
workload, sector controllers, & handoffs

Introduction of ARTS integrated displays and three-level division of labour

NYC ATC Center 1942
flight progress strips



Physical representation of aircraft
call sign, origin, destination, etc.
To aid controller’s memory & mental model (like shrimp boats)

Automated Radar Terminal System (ARTS) Center circa 1975

Incorporates data from radar & flight plans

Displays symbol & text that indicates:
call sign, type of aircraft, destination airport, ground speed, altitude, scratchpad info

Some information on flight strips, some on display

Information updated by radar sweep; information vs. clutter

Three-level division of labour

1. ATC Towers
2. Terminal area approach control facilities (TRACONs)
3. En route centers: Air route traffic control center (ARTCC)

Tower Controller Tasks

- Issue clearance for aircraft to push back from gate
- Confirm schedules/flight plans (already done with flight services, dispatch)
- Takeoff/landing, prior assurance safe separation from other traffic
- Manage ground traffic to/from gate
- Hand off aircraft to/from TRACON

Tower Resources

- Vision: Need clear view of local airspace
  Issues of: Atmospheric perspective, fog, planes that look identical, night vision
- Flight strips: physical representation of aircraft, shows status, move around workstation based on status updates
- Communications: Radio -- always start with aircraft ID, all aircraft can hear messages, allows for a larger mental model of all aircraft position
- Handoffs: Voice used for accept/decline handoff (if runway is not clear), flight strips relayed between tower/radar room, pilot changes radio frequencies, contacts next group

Terminal area approach control facility (TRACON) Tasks

- Manage flow of departing aircraft from tower to en route controller
- Manage flow of arriving aircraft from en route controller to tower
- “Line up” aircraft at regular spacing (in three dimensions)
  1,000 ft vertical, 3-5 miles horizontal
- Different level TRACONS, depending on workload

Need to maintain “***the picture***” – situation awareness

TRACON Resources

- Vision: dark, low contrast environment (to maintain dark adaptation), do not see flights directly
- Automated Radar Terminal System (ARTS)
- Flight strips, present as a backup in case ARTS data tags are lost
- Radio communications, highly standardized
  ATC – pilot & ATC – ATC

En Route Center Tasks (Air Route Traffic Control Centers-ARTCC)

- Handle aircraft over long distances toward destination
- Handle aircraft over areas that do not have radar
- Assist pilots in navigating through navigation waypoints (VOR navigation signals)
- Maintain separation of 5 miles and 1,000 or 2,000 vertical
- Laid over top of any local TRACON sector
- Deliver aircraft to destination TRACON, without overloading the TRACON station

En Route Center Resources

(Similar to TRACON)
Flight strips
Radio communications
HOST computer, radar (plan view display/PVD), flight data, & “snail trail” of past trajectory

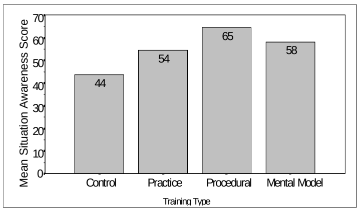
Training SA in ATC

Simulated ATC task

3 types of training

- Practice
- Procedural (if-then rules)
- Mental model (general principles & goals)

Effects on SA



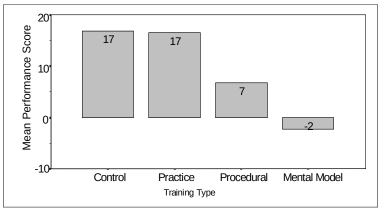
Training SA in ATC

Simulated ATC task

3 types of training

- Practice
- Procedural (if-then rules)
- Mental model (general principles & goals)

Effects on error rate



Current Applied Cognitive Issues in ATC

- Perception, temporal distortion, & channelised attention
- Vigilance, distraction, habituation, & fatigue
- Displays, symbology, communications, & problem solving
- Workload, situation awareness, & stress
- Shift changes & handovers