



Live-Virtual-Constructive Simulation Framework for Testing and Evaluation of Air Combat Tactics, Techniques and Procedures

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Testing and evaluation (T&E) of air combat tactics, techniques and procedures (TTPs)

- Flight's primary goal in air combat:
Maximize probability of kill (Pk) and probability of survival (Ps)
- Primary goal achieved by following TTPs
- Challenges of using only live, virtual or constructive simulations for T&E of TTPs:

Constructive only

- Does not reveal the impact of human-machine interaction

Virtual only

- Time consuming
- Labor heavy

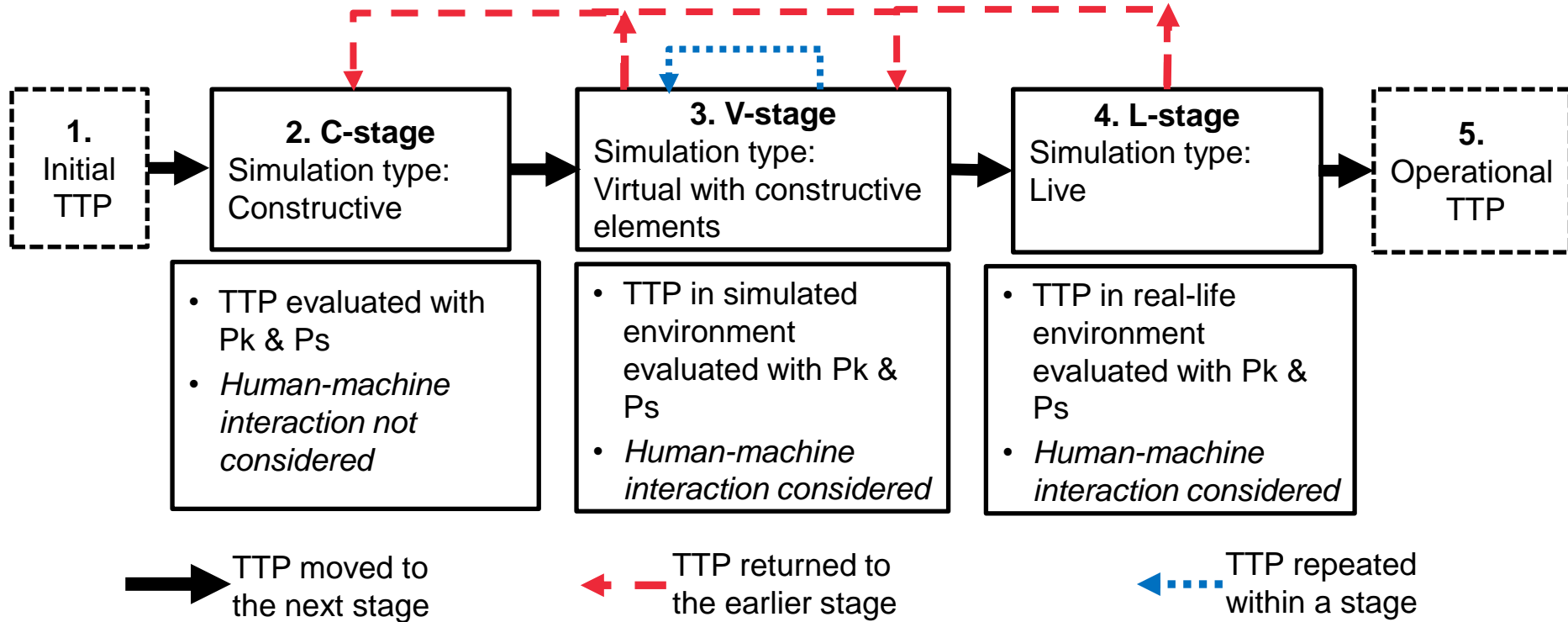
Live only

- Expensive
- Potentially unsafe

Our new simulation framework for T&E of air combat TTPs

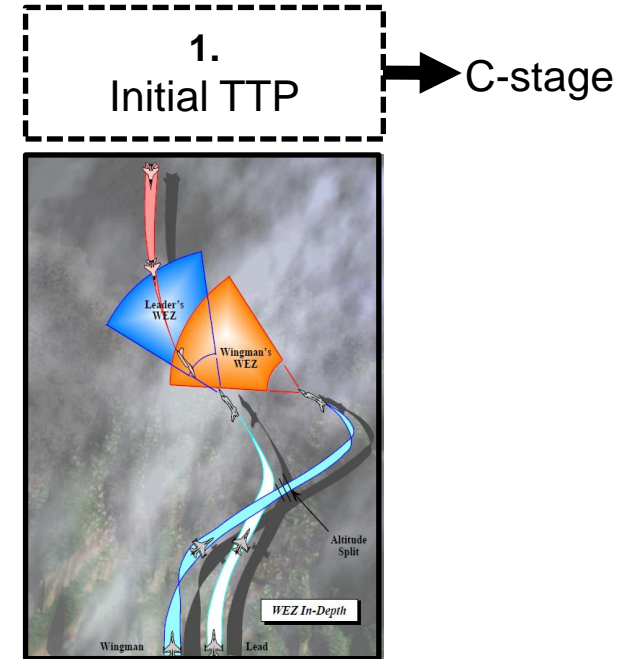
- Iterative development of TTPs using separate live, virtual and constructive simulations
- TTPs evaluated w.r.t
 - Primary goal, i.e., Pk and Ps
 - Human-machine interaction reflecting pilots' abilities and limitations to interact with aircraft and systems

The Live (L) - Virtual (V) - Constructive (C) Simulation Framework



Initialization of TTP T&E

- Definition of air combat scenario
 - Friendly and enemy aircraft and systems
 - Enemy TTP
- Definition of initial TTP
 - = Set of quantitative and qualitative rules
 - Example quantitative rule: “Airspeed at missile launch must be Mach 0.9”
 - Example qualitative rule: “Flight members must communicate their tactical status”
- Selection of ...
 - Flight members whose TTPs are of interest
 - TTP rules to be modified

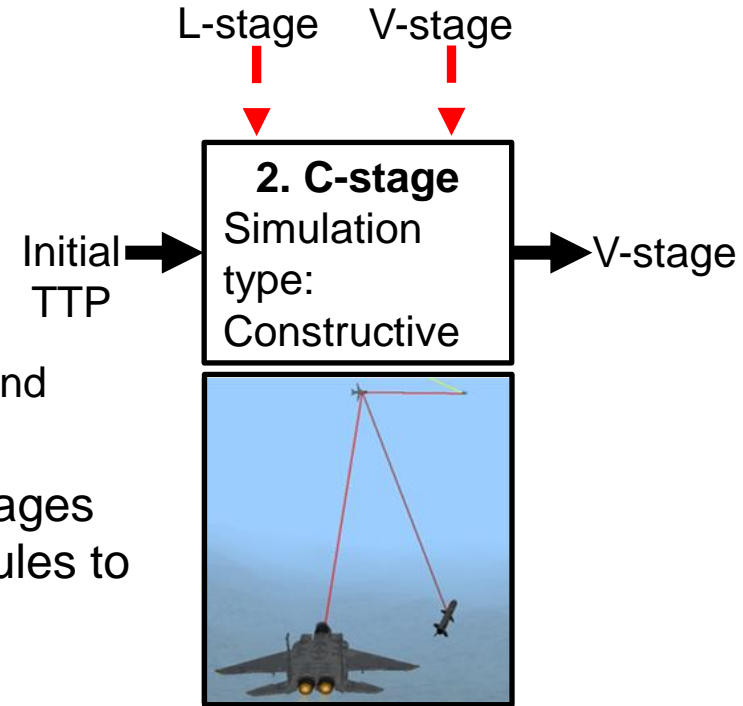


Human-machine interaction measures of TTP in V- and L-stages

- Pilot's Normative Performance (NP): TTP adherence by pilot
 - NP measure consists of a set of TTP rules
 - Score based on pilot's accuracy of adhering to rules
- Pilot's Situation Awareness (SA): Level of agreement between pilot's understanding of scenario's state and scenario's actual state
 - SA measure consists of a set of probes "Did you correctly perceive/understand/anticipate..."
 - Pilot attends debrief
 - 1) Mission playback paused at predetermined times
 - 2) Pilot answers probes using cockpit recordings and scenario's actual state => Score
- Pilot's Mental Workload (MWL): Imbalance between demands of flying task and pilot's cognitive resources
 - MWL measure (NASA-TLX) consists of six dimensions scored by pilots
 - mental demand, physical demand, temporal demand, frustration, effort, performance

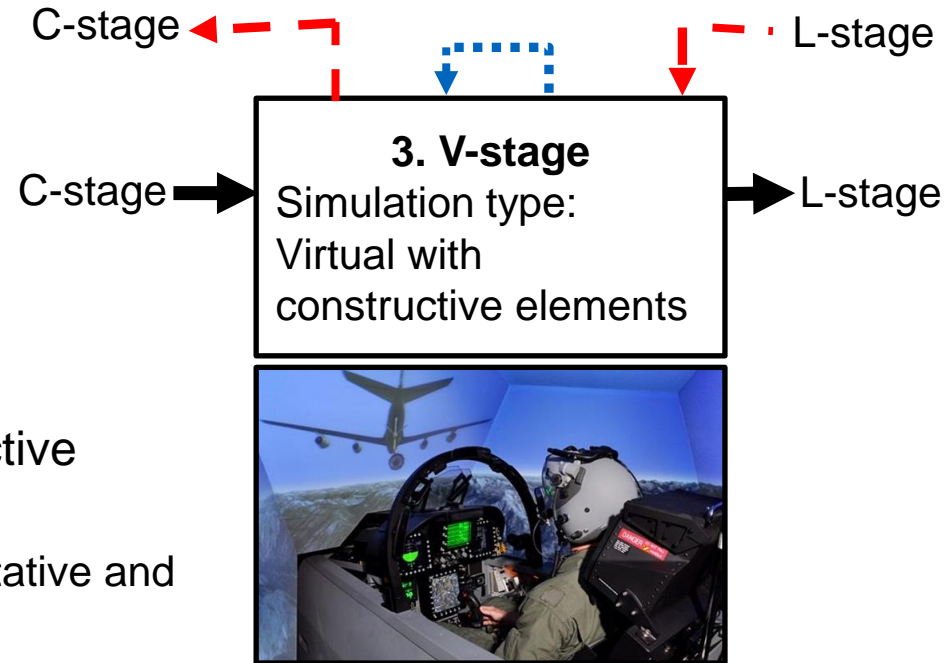
Constructive (C) -stage

- Quantitative rules
- Enemy aircraft follow defined TTP and scenario
- First C-stage
 - Optimal values of quantitative rules maximizing P_k and fulfilling constraint $P_s=1$
- Unsatisfactory SA, MWL, NP, P_k , P_s in V- or L-stages
=> V- or L-simulation results reveal quantitative rules to be adjusted
- Repeated C-stage
 - Optimal values of quantitative rules minimizing $(P_k - P_{kref})^2$ and fulfilling constraint $P_s=1$
 - P_{kref} based on earlier V- or L-stages and optimal values of P_k in earlier C-stages



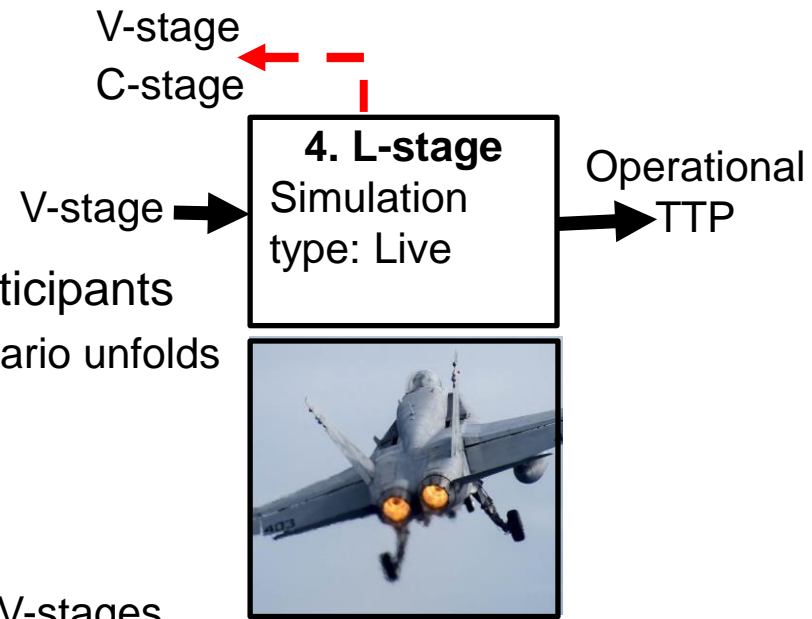
Virtual (V) -stage

- Quantitative and qualitative rules
- Pilots whose TPP is of interest fly V-simulator as participants
 - Pilots' NP, SA and MWL recorded
 - Flight's Pk and Ps estimated
- Other aircraft implemented as constructive simulation entities
 - Friendly aircraft follow predefined quantitative and qualitative rules
 - Enemy aircraft follow same TTP and scenario as in C-stage
- Unsatisfactory NP, SA, MWL, Pk, Ps => TTP rules for revision identified
 - Modification of quantitative rules => TTP returned to C-stage
 - Modification of qualitative rules => V-stage repeated with modified qualitative rules
- Satisfactory outcome of V-stage => TTP to L-stage



Live (L) -stage

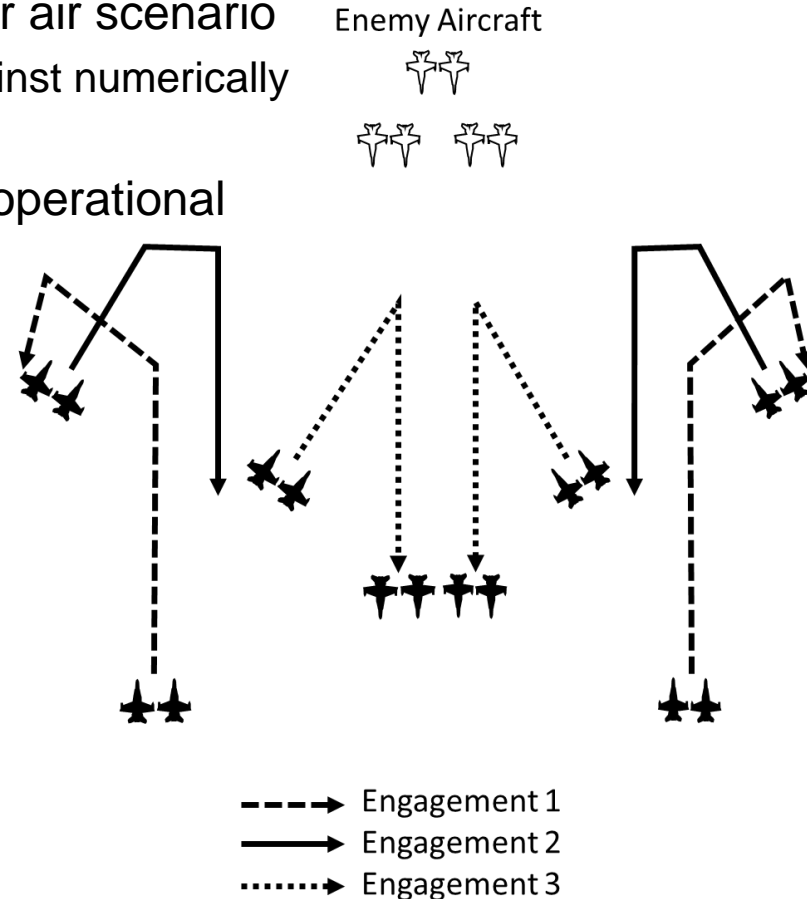
- Quantitative and qualitative rules
- Pilots whose TTP is of interest fly aircraft as participants
 - Standard flight briefing given but not told how scenario unfolds
 - Pilots' NP, SA and MWL recorded
 - Flight's Pk and Ps estimated
- Supporting friendly and enemy pilots
 - Briefed to follow TTP and scenario used in C- and V-stages
- Unsatisfactory NP, SA, MWL, Pk, Ps => TTP rules for revision identified
 - Modification of quantitative / qualitative rules => TTP returned to C-stage / V-stage



- Satisfactory outcome of L-stage → **5. Operational TTP**

Demonstration of the L-V-C simulation framework

- Beyond-visual-range (BVR) defensive counter air scenario
 - Three seamlessly connected engagements against numerically superior enemy
- Initial TTP defined based on existing tactical operational procedures
- *Development of wingmen's TTP rules*
- Enemy
 - Modern air superiority fighters
 - TTP for neutralizing friendly aircraft
- Simulations conducted with
 - C: Air Combat Evaluation Model (ACEM)
 - V: Weapon Tactics and Situation Awareness Trainer (WTSAT)
 - L: F/A-18C aircraft



First constructive and virtual stages

First C-stage

- Optimal values of quantitative rules “*Missile launch ranges*”, “*Evasive maneuver ranges*” and “*Egress phase durations*”
 - $P_k = 0,73$ & $P_s = 1,00$
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First V-stage

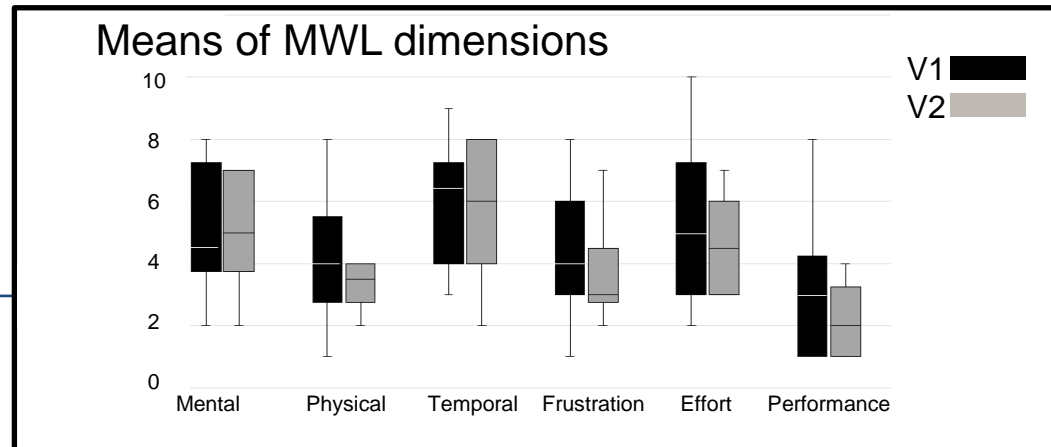
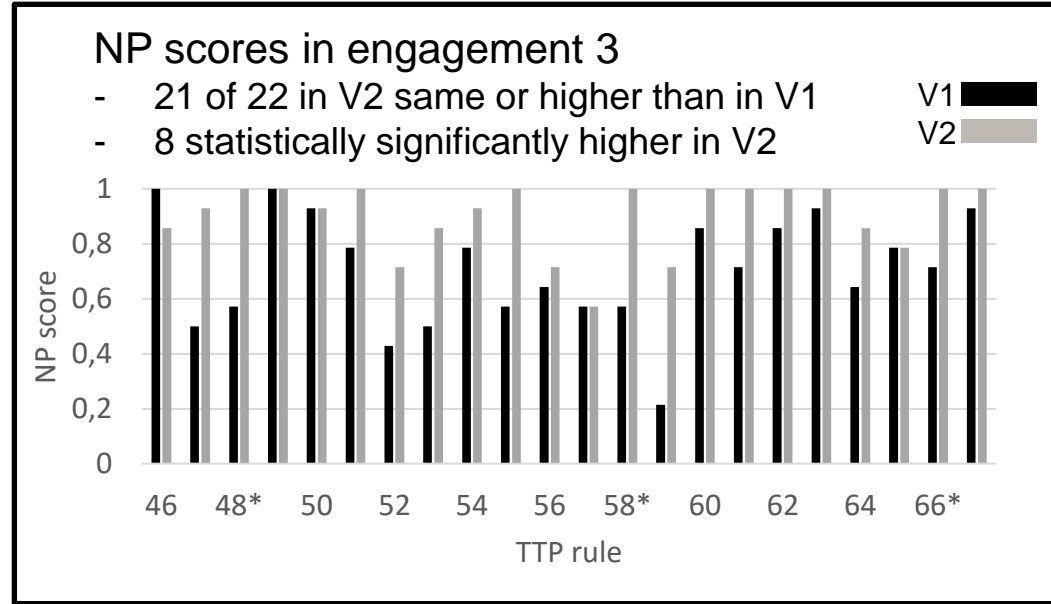
- 14 combat ready F/A-18 pilots
 - $P_k = 1,00$ & $P_s = 1,00$
 - NP, SA and MWL means of single rules, single probes, single engagements and whole mission calculated and analysed with suitable statistical methods ...
 - Main findings – need to modify...
 - quantitative rule “*Missile launch range in engagement 1*”
 - qualitative rules “*Communication of tactical status in engagements 1, 2 and 3*”
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Second C-stage

- Max P_k replaced with $\text{Min}(P_k - 0,70)^2$
 - Optimal value of “*Missile launch range in engagement 1*” increased by 17% => 11,2 seconds more time for engagement 2
 - $P_k = 0,70$ & $P_s = 1,00$
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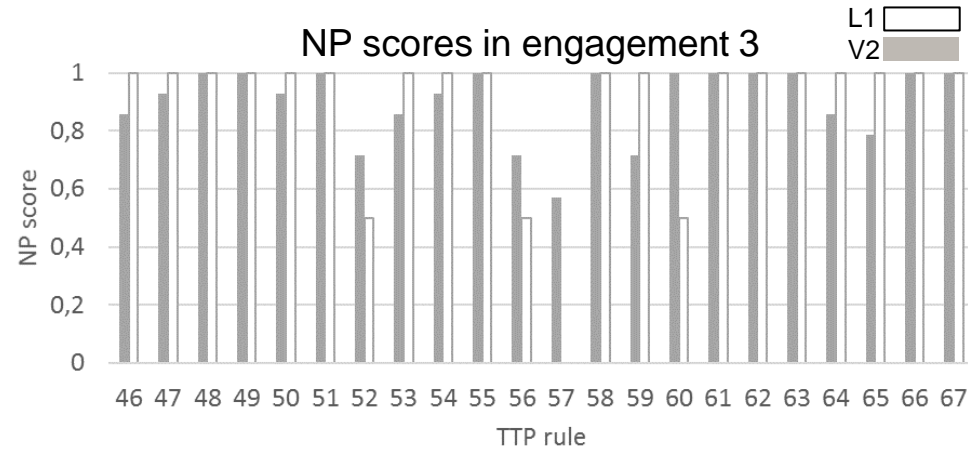
Comparison of first (V1) and second virtual (V2) stages

- New group of 14 combat ready F/A-18 pilots in V2
 - Pk=1,0 & Ps=1,0 in V2 and V1
 - NP means mostly higher in V2 than in V1
 - E.g. overall mean statistically significantly
 - SA means mostly higher in V2 than in V1
 - E.g. mean in engagement 2 statistically significantly
 - Means of all MWL dimensions lower in V2 than in V1
- => V2 TTP superior to V1 TTP*



Comparison of second (V2) virtual and first live (L1) stages

- Two combat ready F/A-18 pilots in L1
 - Two 4 vs. 8 air combat conducted
 - No statistical comparison
- $P_k=1,0$ & $P_s=1,0$ in L1 and V2
- 56 of 67 NP scores in L1 \geq in V2
- 38 of 45 SA scores in L1 \geq in V2
- Means of MWL dimensions in L1 $>$ in V2
- TTP used in L1 leads to ...
 - ... satisfactory P_k and P_s
 - ... NP, SA and MWL scores reflect V2
 - => *Operational TTP!*



Benefits of the L-V-C simulation framework

- Cost-effective and safe decision support tool for making decisions about TTP's modifications and operational approval
 - TTP developed iteratively in separate C-, V- and L-simulation stages
 - Impact of pilot behaviour in human-machine interaction evaluated with TTP adherence (= normative performance), SA and MWL
- Use of multiple simulation classes and measures
 - Increases transparency, reliability and validity of simulation study
 - Eases interpretation of simulation results
 - Minimizes impact of individual models' inaccuracies
- Similar principles can be applied to civil or military simulation task where human-machine interaction is of concern

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Live-Virtual-Constructive Simulation for Testing and Evaluation of Air Combat Tactics, Techniques and Procedures, Part 1: Assessment Framework

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