SAFEVAC: A FRAMEWORK FOR SAFE AERIAL MEDICAL EVACUATION OF HEMODYNAMICALLY UNSTABLE PATIENTS

HMSRS 2026

Lonnie G Petersen MD PhD

PI: Aerospace Physiology Lab

Aeronautics and Astronautics, MIT

Health Sciences and Technology, Harvard-MIT

Disclosure

- Lonnie G Petersen has no conflicts to report
- Benjamin McCloskey has no conflicts to report
- Michael L Tibbs has no conflicts to report

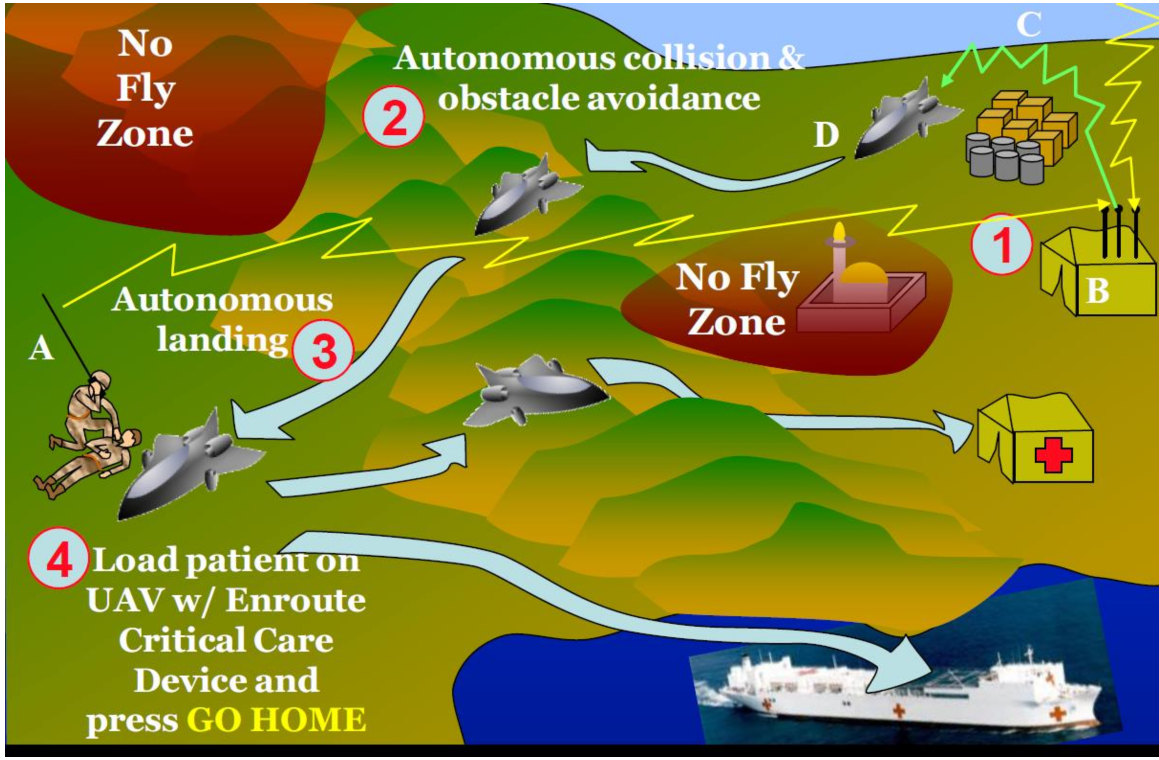
- *The views expressed are those of the authors and do not reflect the official views of the United States Air Force, nor the Department of Defense. Mention of trade names, commercial products, or organizations do not imply endorsement by the U.S. Government. The authors declare no conflict of interest.*

Motivation and Outline

- Increased demand for aerial medical/casualty evacuation both in civilian and military setting
- Currently operating at 4:1 ratio -> does not scale(!)
- Future mass causality scenarios depend on automation and autonomy incl tools for triage, route planning, and flight trajectory optimization
- Patients are currently considered "cargo"
- We need **physiology-aware systems**, especially as we transition to autonomous aircraft
- Today -> Overview pipeline of research from Aerospace Physiology Lab, MIT

Background

- Aviation induces stress on the human body (e.g., acceleration, vibration), specially during fast flight or evasive maneuvers (congested/contested air-space)
- Patients have reduced tolerance to environmental stress, but we currently have no data to quantify and thus mitigate
- We need to:
  1) Understand the impact of flight on patients
  2) Create computational models to facilitate autonomy
  3) Novel way to monitor and predict clinical status to facilitate triage and trajectory planning

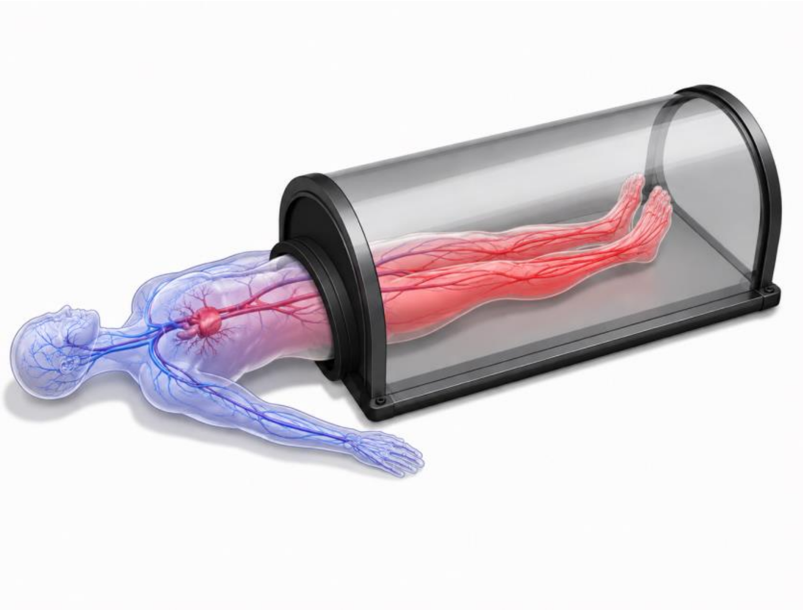


NATO vison for future automated aerial CASEVAC. The Safe Ride standards doc outlines requirements and gaps

Understand relevant patient physiology

Human data – controlled environment

- Hemorrhage is the #1 cause of preventable death both in warfighters and civilians (40% of combat fatalities, 30-40% of civilian trauma fatalities; 2 mill fatalities pr year)
- Hemodynamic unstable (hemorrhage) are particularly susceptible to G-forces
- **Create a test platform** to allow us to study combined effect of simulated bleeding (LBNP) and relevant G-profiles in the long-arm centrifuge

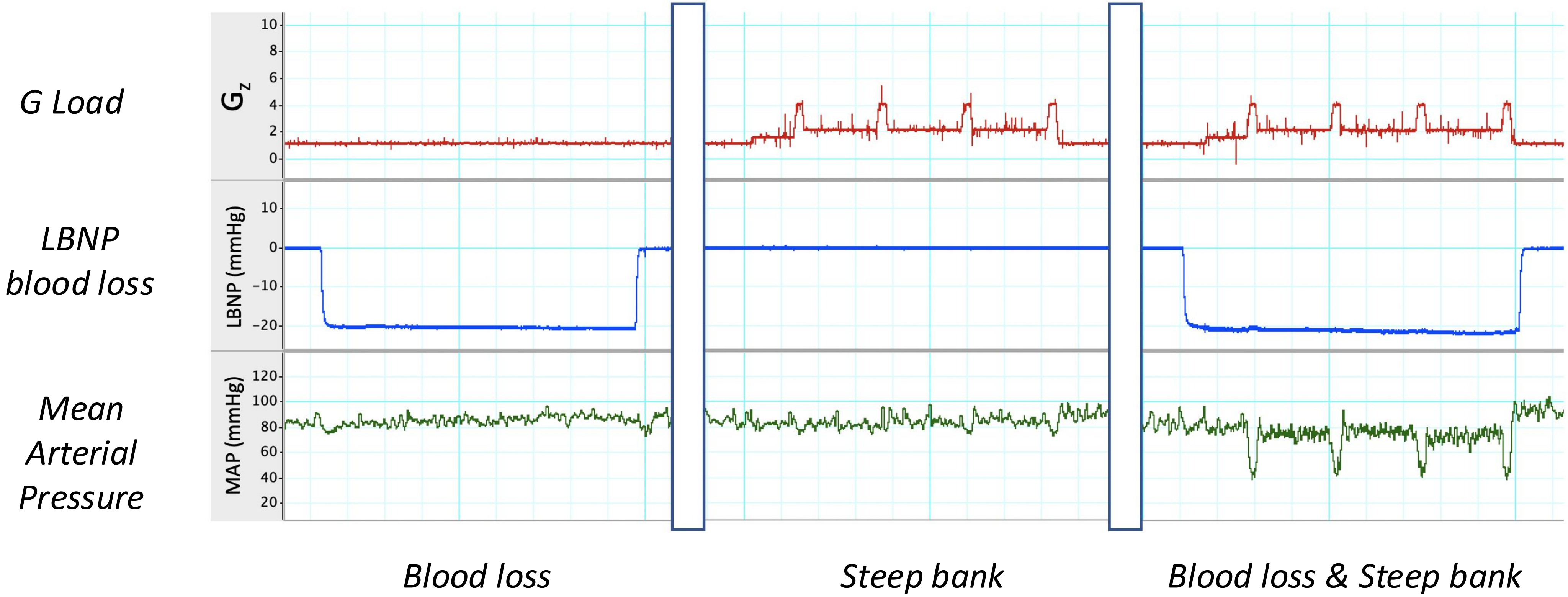


Aerospace Physiology Laboratory

Human data – controlled environment

- Multiple centrifuge trials: Quantify reduction in tolerance by applying relevant G-profile -> 10%, 15% and 25% hemorrhage (LBNP) -> same G-profile: delta values.

Human data



Morse et al 2024, Petersen et al 2024, Tibbs et al 2025, Tibbs et al 2026

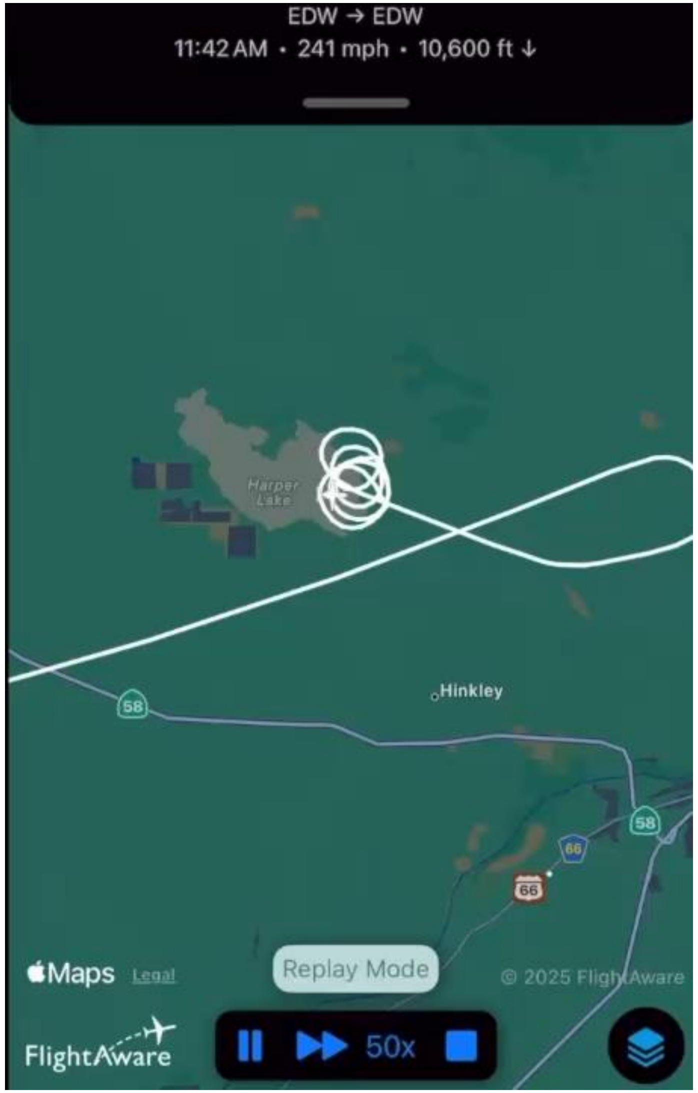
AEROSPACE PHYSIOLOGY LABORATORY

Flight testing

In-air: G-forces, vibration, altitude, noise, tp, objective vs perceived flight incl risk

Muddy – but realistic

Flight test: USAF and Test Pilot School



Evasive profile: healthy and simulated hemorrhage

- **Airworthy test platform**: methodology and Pentagon IRB
- 9 sorties, 28 flight hours: First human data simulated casualty in-air
- Confirming synergistic impact of hemorrhage and G and established the dose-response relationship

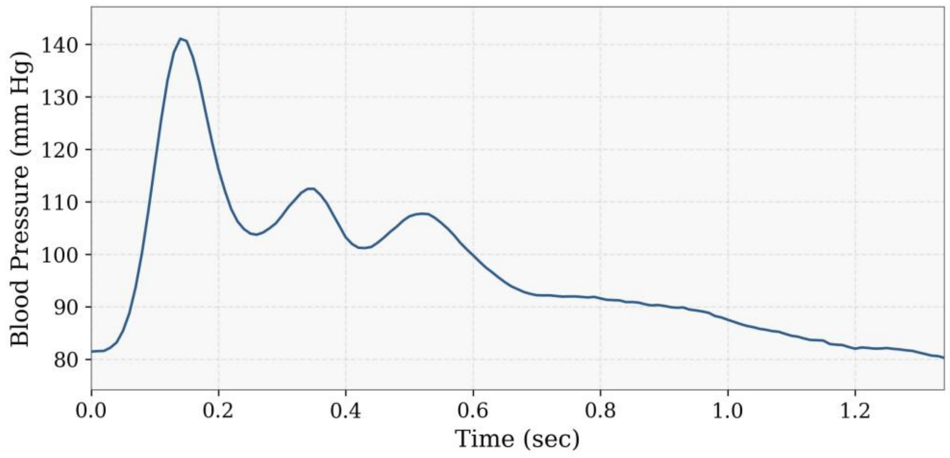
Lower Body Negative Pressure Device (LBNP)

US Air Force C-12J

Tibbs et al 2025 and 2026

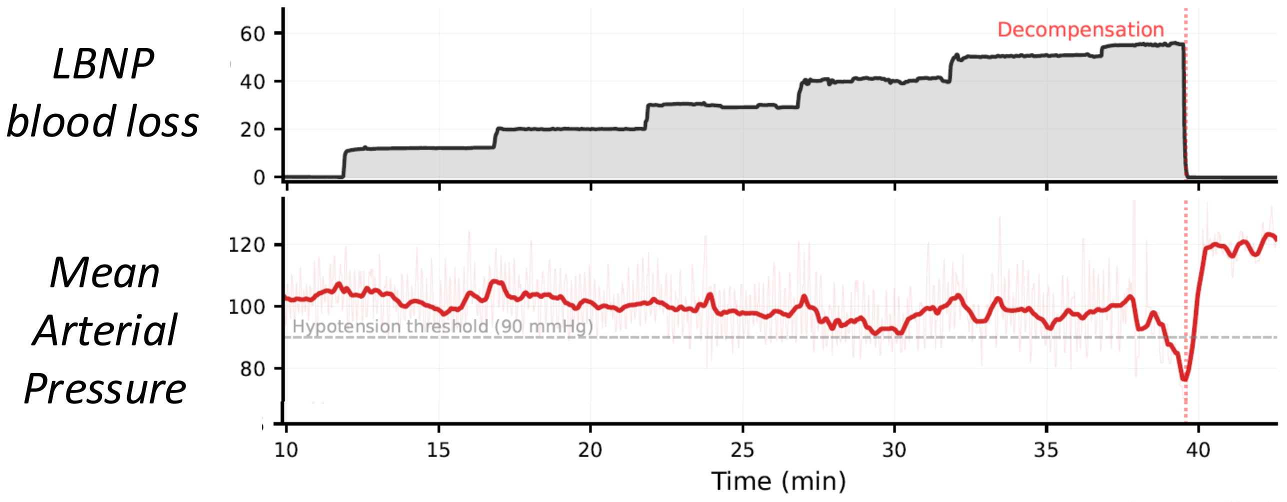
Limitation of blood pressure

- BP drops when reserve capacity is exhausted (30-40% blood loss)
- Need to get ahead of the curve
- G-adjustisted Compensatory Reserve Measurement (GCRM) indication of remaining ability to compensate for blood loss
- Waveform analysis



Classification of Hemorrhage

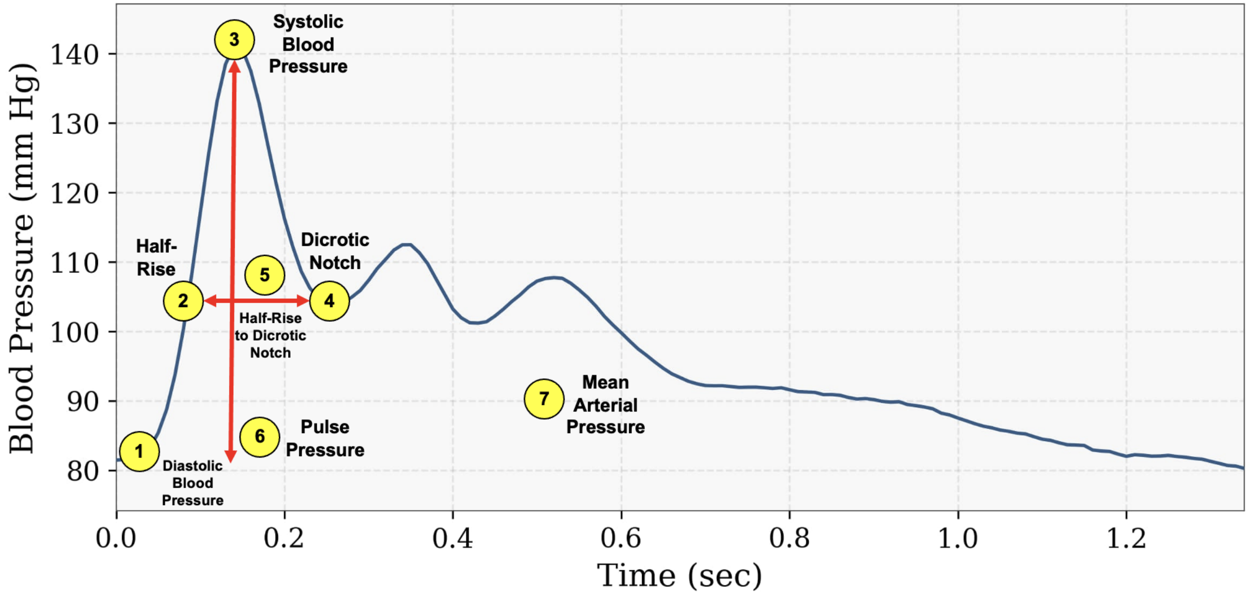
	Class I	Class II	Class III	Class IV
Blood loss (ml)	<750	750–1500	1500–2000	>2000
Blood loss (%)	<15	15–30	30–40	>40
Heart rate	<100	>100	>120	>140
Blood pressure	Normal	Normal	Decreased	Decreased
Pulse pressure	Normal	Decreased	Decreased	Decreased



Tibbs et al 2026

Human Reserve Capacity

- Specific features from waveform predict blood pressure collapse
- We created an algorithm to indicate G-adjusted compensatory reserve capacity (GCRM) from our centrifuge and flight data
- GCRM: unitless value 0-1.
- Interpretation: 1=healthy; 0.7=pay attention; 0.4=critical; 0.1=high risk of death; 0=dead



$$\mathrm{CRM}(t) = 1 - \frac{\mathrm{BLV}(t)}{\mathrm{BLV}_{\mathrm{HDD}}}, \quad \mathrm{CRM}(t) \in [0,\ 1]$$

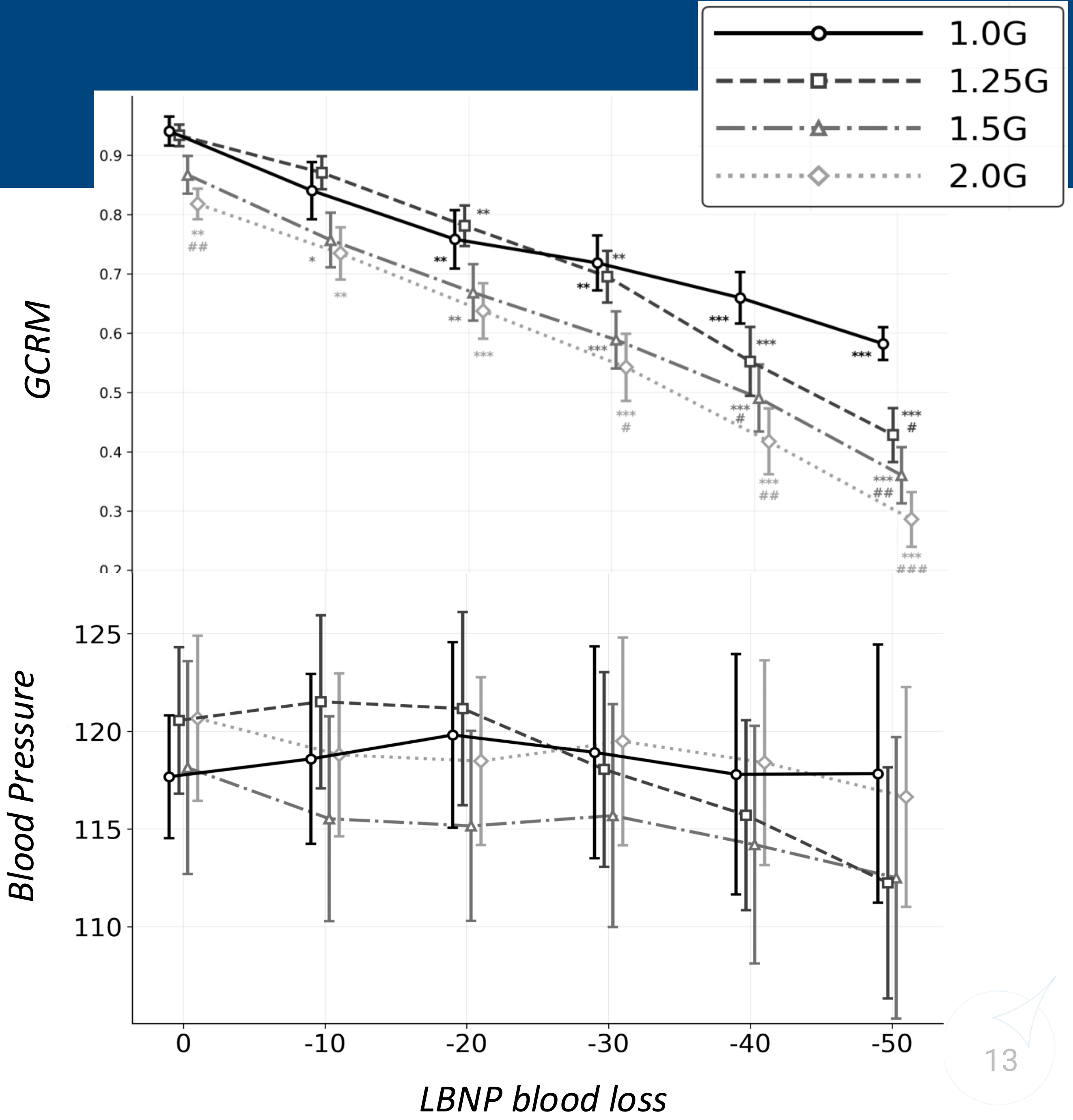
BLV(t): blood loss vol at t; BLV_{HDD}*: blood vol loss at decompensation*

Tibbs et al 2026: Breaking the Black box: Interpretable AI Achieves Superior Hemorrhage Detection with the Compensatory Reserve Measurement

Blood pressure vs GCRM in-flight

- Progressive levels of blood loss
- Different G-levels from 1G to 2G
- In-flight data

- BP is relatively maintained
- GCRM is a better indicator for G sensitivity and blood loss (2G vs 1G)
- Inform flight trajectory (before we kill the patient)

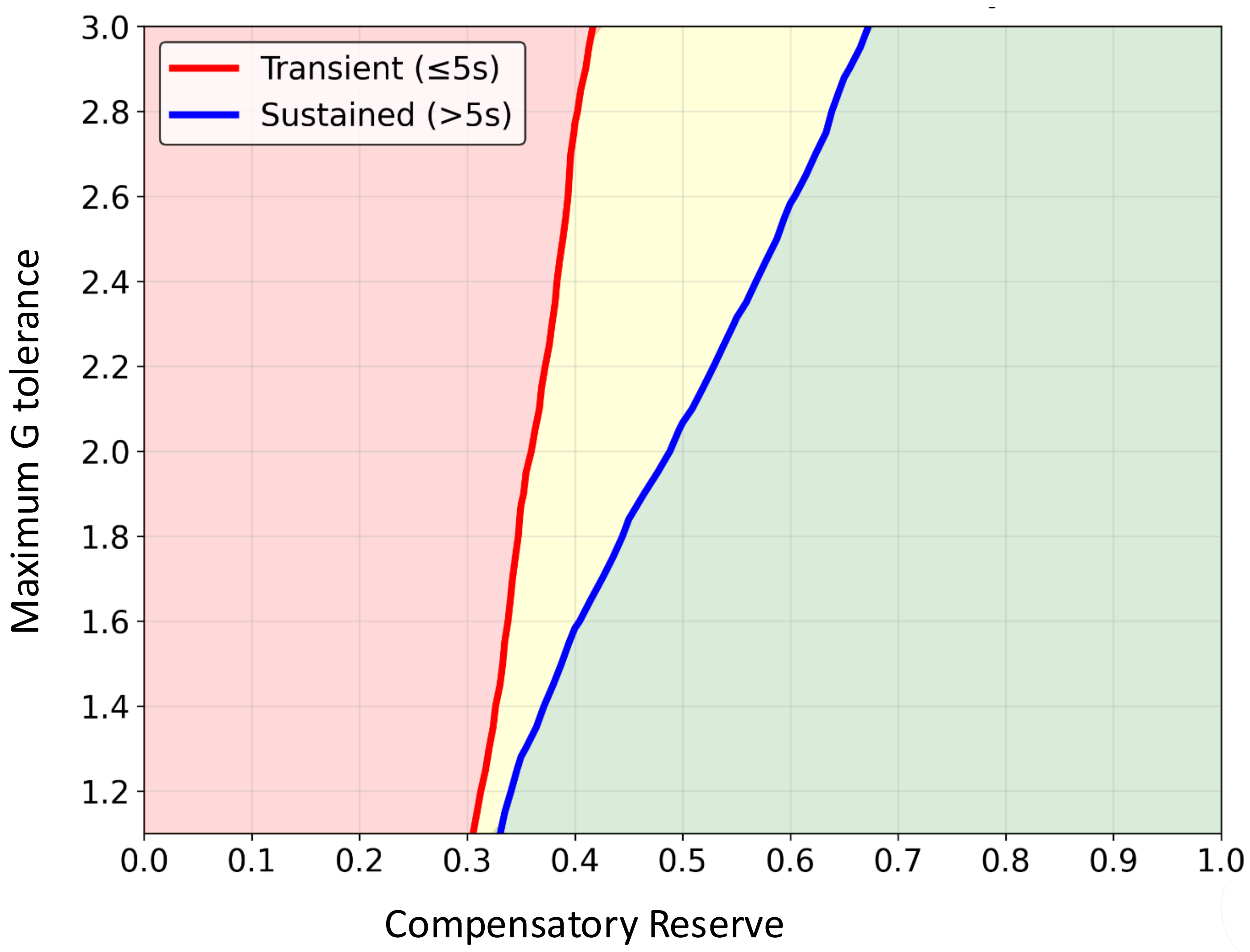


Recent data - unpublished

AEROSPACE PHYSIOLOGY LABORATORY

Dose-response relationship. Triage and planning tool

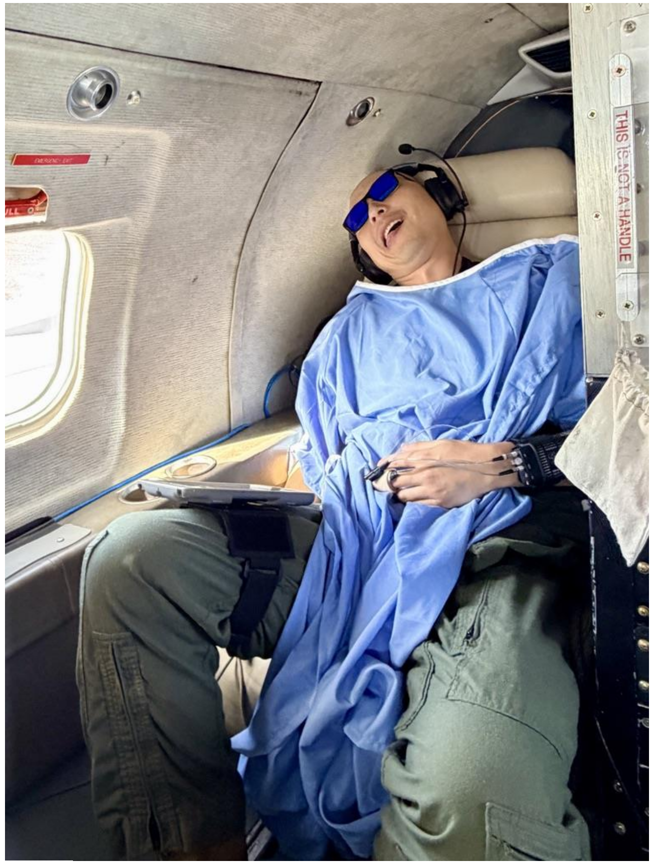
- Example of use:
  - Operational planning tool (design credit: test pilots)
  - G as a function of patient's reserve capacity
  - Sustained G vs brief bank
- But also: Input for pilot and Guidance, Navigation, and Control
- Can we fly based on patient status? **Paradigm shift!**
- Automate for autonomy



More flight testing

Initial steps: Using patient status to guide flight

Use understanding of pt status to optimize flight

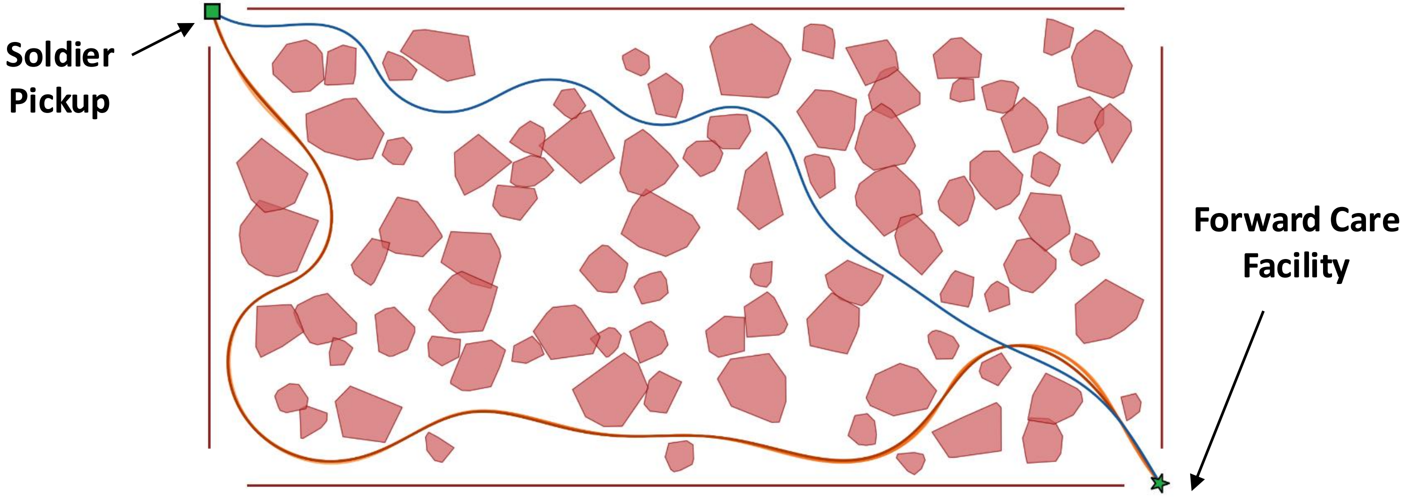


Test Pilot School: Testing how to use patient data to guide flight

Demanding track (no-fly zones) and progressive blood loss

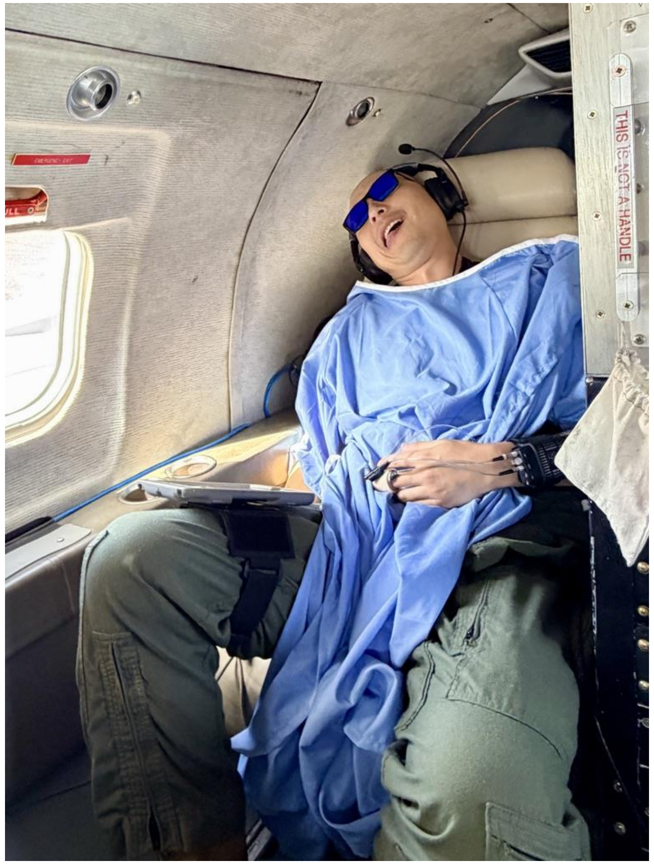
Real human, real blood pressure input

Algorithm overlay augment GCRM crash



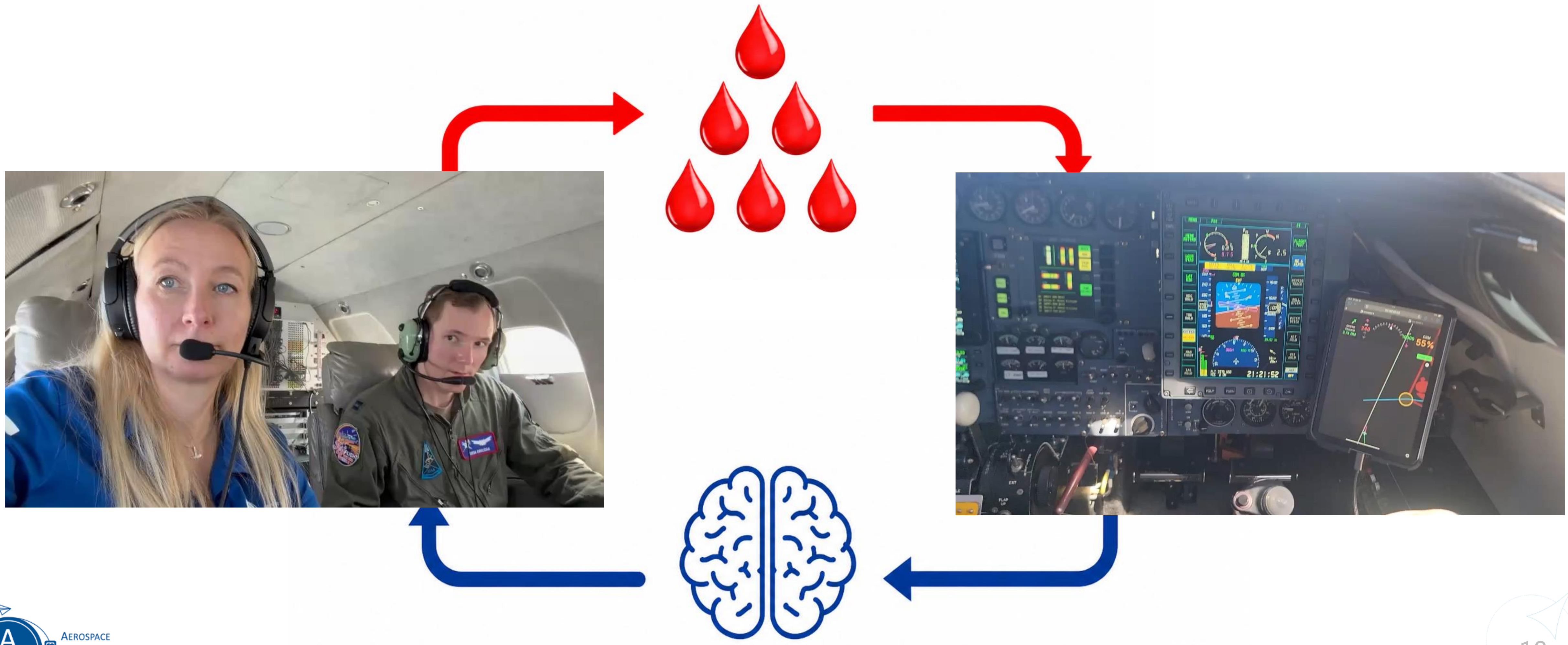
AEROSPACE PHYSIOLOGY LABORATORY

Flight test: human pilot vs auto



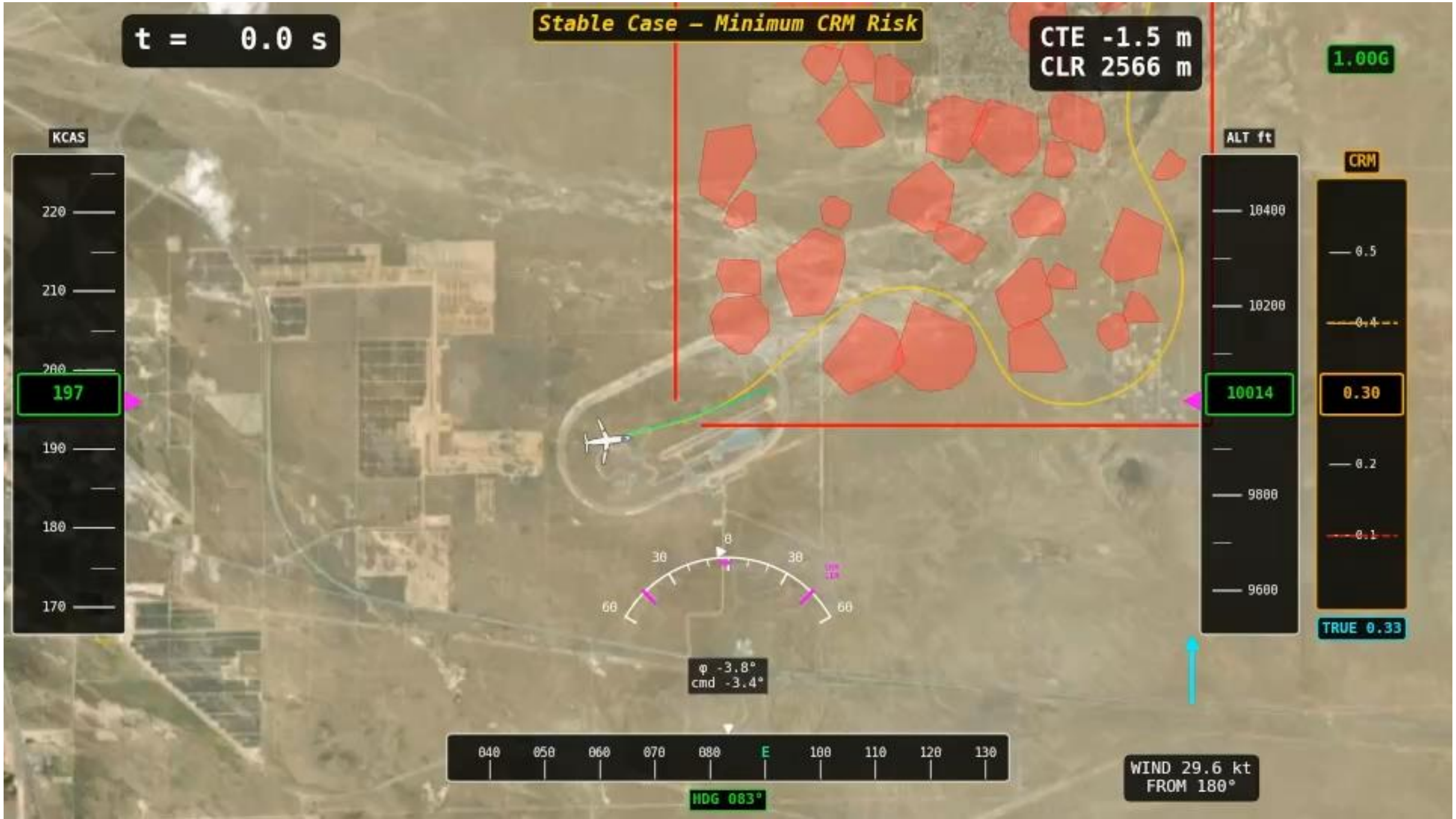
18 sorties, 18 test-pilots and 18 patients, 34 flight hours

Flying based on pt data: human vs auto



Aerospace Physiology Laboratory

Preview:
Physiologically Aware Trajectory Optimization, Guidance and Control



Prelim results (more data next year)

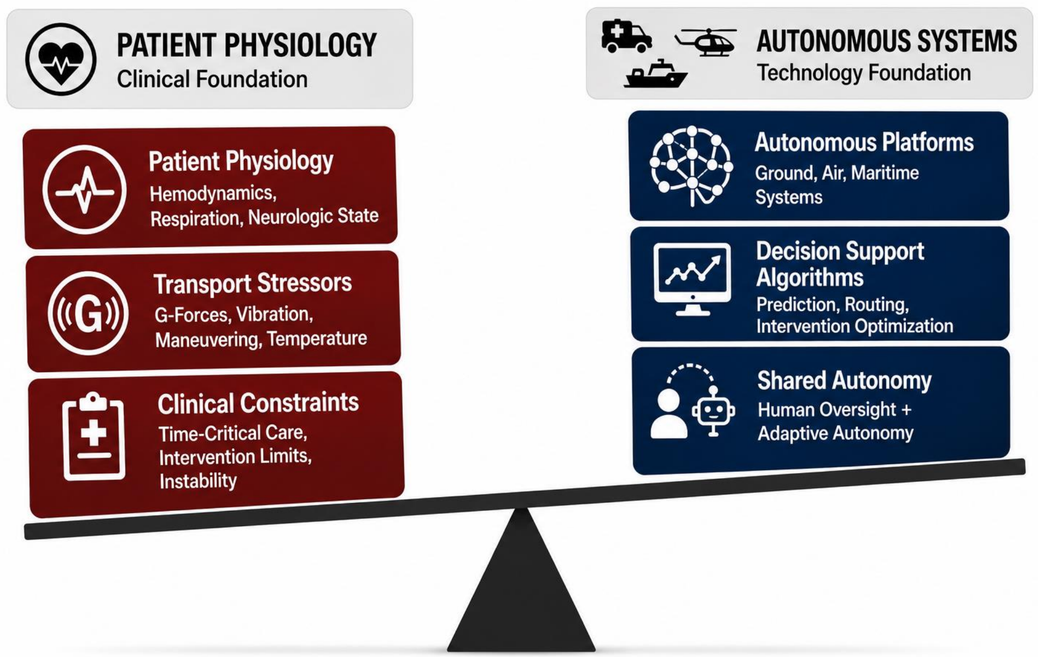
Mode	N	CRM kills	Obs hits	Total kills	Kill rate
(pilot)	61	25	40	46	75%
(auto)	79	26	0	26	33%

Unpublished

Aerospace Physiology Laboratory

Conclusion

- Automation and autonomy is required to meet growing need for aerial CASEVAC
- To increase efficacy and safety we must transition to a patient physiology-centered approach
- Main take away
  - Synergistic effect of hemorrhage and acceleration
  - Novel methods to monitor and predict patient status are warranted; GCRM is a promising parameter
  - Paradigm shift is needed to integrate patient status into flight trajectory optimization
  - We have shown how patient data can support both: Pilot decision making and autonomous flight guidance and navigation to optimize flight



Thank you for your attention. Additional question: lgpeters@mit.edu