Virtual-Integrated Twin for Autonomous Lifesaving (VITAL)

Roozbeh Jafari, PhD

Industry Day

March 31, 2026

DARPA

Proposers' Day Objectives

- The Proposers' Day briefing is intended to provide an orientation to the VITAL Program Solicitation and is solely for information purposes
- **The program solicitation (PS) supersedes anything presented or said by DARPA at the Proposers' Day**
- The PS will be released within the coming weeks, please keep in mind there will be a continually updated FAQ for clarifying information
- Examples in this briefing (e.g., technologies, use cases) are chosen for ease of illustration only and do not constitute endorsement of any particular approach
- Interested performers are expected to be able to articulate a clear and compelling vision for their technology, proposed course of research, and transition potential
- **Teaming is important! Today is a great opportunity for networking**
- We need your help to make this program a success!

Frequently Asked Questions (FAQs)

- Please **submit all your questions** about program details via **VITAL Program E-mail (VITAL@darpa.mil)**. The team will compile, and we'll hold a discussion session at the end of the day and run through them then.

- We will make every effort to answer your questions quickly. All questions (as determined appropriate) will be addressed in the **FAQ on the opportunity website**.

Teaming is Important

- To fully address the PS, you may need to team with other entities
- Each team should submit a unified proposal under a single PI
- Individuals or organizations may team with one or more prime organizations as long as they are not also submitting a proposal as a prime
- You must find your collaborators on your own, and today is a great opportunity for networking!

VITAL Team Member Introductions and Abstract Due Date

DARPA VITAL Team	
Roozbeh Jafari, PhD	DARPA/BTO Program Manager
MAJ Senthil Mudaliar, MD MBA MPH M.Eng	DARPA/BTO Deputy Program Manager to Roozbeh Jafari
Dimas Pinzon	DARPA/BTO Chief of Staff to Roozbeh Jafari
Jason Allio	DARPA/BTO Program & Financial Support
Bethany Travis	DARPA/BTO Program Security Representative
Lisa McIlrath, PhD	DARPA/BTO Technical SETA
TJ Hinton, PhD	DARPA/BTO Technical SETA
Anna Skinner, PhD	DARPA/BTO Technical SETA


Roozbeh Jafari, PhD


Senthil Mudaliar, MD


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TJ Hinton, PhD


Anna Skinner, PhD

<u>Abstracts Due:</u> Wednesday, April 22, 2026, 5:00pm EDT

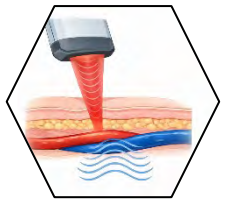
VITAL Program Vision

H1

BIOLOGICAL TECHNOLOGIES OFFICE

Measurement

Imaging

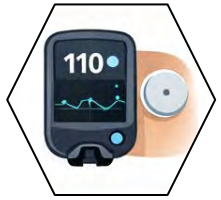


Ultrasound

Optical

Electro-physiology

Chemical



Input

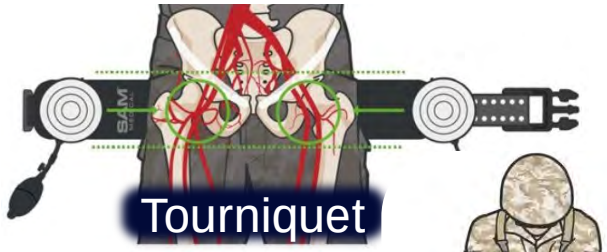
Hemorrhage / Shock OR Heart Failure

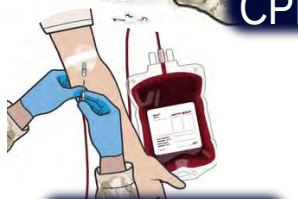
Lightweight, Real-Time Model

- Physiologic State Estimation
- Predictive Simulation
- Uncertainty Analysis

Action Optimization

Interventions





Enhanced measurements + predictive insights + decision support

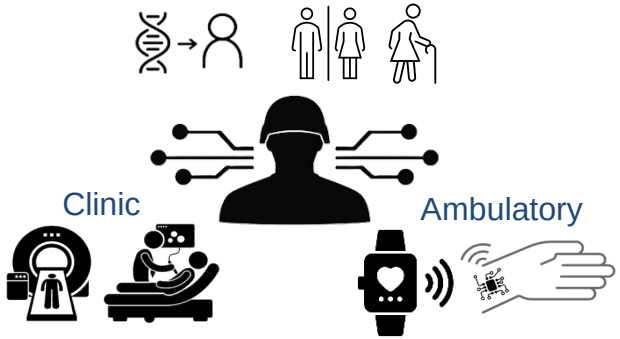
TXA: Tranexamic acid; CPR: Cardiopulmonary Resuscitation

VITAL: Digital Twin

Physical → Virtual

Sensor fusion at POC, data assimilation under power/bandwidth constraints, inverse problems

Genetic & Demographic



Operational Context

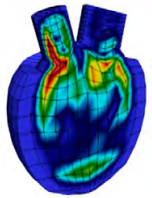
Echelons of care, sensors and observing systems, data acquisition, and data integration

Human-digital twin interaction

Trauma detection

Intervention optimization

Prevention of complications



Patient-specific Model

Modeling & Analytics

first-principles, mechanistic, and empirical models, adaptive calibration

Human-in-the-loop decision making

Virtual → Physical

Forecast patient trajectories, recommended interventions & timing, resource allocation

Augmented sensing, predictive insights, skill/role-aware decision support

POC – Point of Care

SOTA Modeling: Digital Twins for Hospital Settings

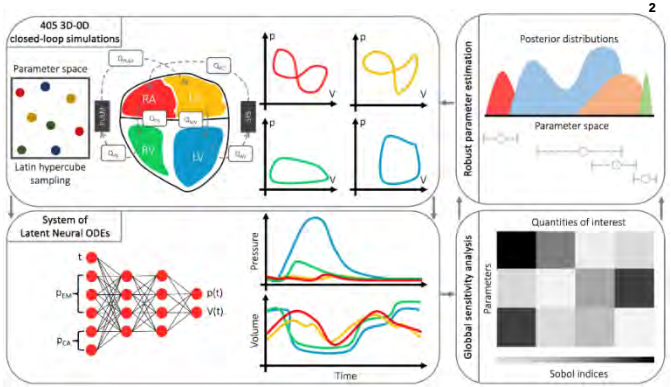
H2

BIOLOGICAL TECHNOLOGIES OFFICE

State of the Art (at Hospital)

High Fidelity (HF) DTs exist (e.g., to predict heart failure)

1



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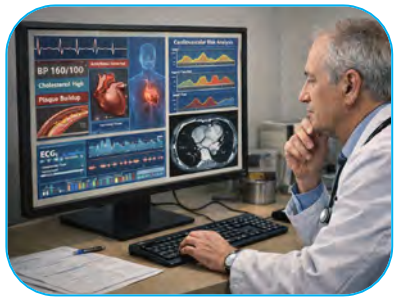
[1]Fedele, Marco, et al. Computer Methods in Applied Mechanics and Engineering 410 (2023): 115983.

[2]Salvador, Matteo, et al. NPJ Digital Medicine 7.1 (2024): 90.

Their construction and interpretation require:

Non-ambulatory Sensors

Compute Resources



Clinical Expertise

Limitations for Point-of-Care Intervention

- SOTA models strive for highest fidelity, not minimum required data
- HF model updates require sophisticated non-ambulatory sensors
- HF models require high computational cost
- First responders lack clinical expertise

Hospital-based DTs require models, sensors, compute resources, and expertise that don't exist at PoC

POC: Point of Care
SOTA: State-of-the-art
DT: Digital Twin

Current Practices Rely on Population-level Thresholds for Prognostic Assessment

Unmet Needs

Medics speak with injured Ukrainian serviceman Vitalii after treating him at a stabilization point. Source: Reuters

- ❑ Scalable clinical decision support for medics for diverse trauma conditions
- ❑ Individualized physiological discriminators
- ❑ Focus on dynamic trajectories
- ❑ Context-aware decision support for polytrauma management
- ❑ Ensure objective outcome metrics

Indicator	Good Recovery	Poor Recovery
Mean Arterial Pressure (MAP)	≥ 65 mmHg (maintained without vasopressors)	< 60 mmHg (requiring continuous vasopressor support)
Systolic Blood Pressure (SBP)	> 90 mmHg and stable	< 90 mmHg despite fluids/pressors
Heart Rate (HR)	60–100 bpm (normalizing with perfusion recovery)	>120 bpm (persistent tachycardia indicating shock)
Capillary Refill Time	< 2 sec (adequate perfusion)	> 3 sec (poor peripheral perfusion)
Urine Output	> 0.5 mL/kg/hr	< 0.3 mL/kg/hr (suggestive of renal hypoperfusion)

Hemodynamic Stability Following Hemorrhagic Shock Based on Population-Level Thresholds (2-7 Days)

Bonanno, F.G. Management of Hemorrhagic Shock: Physiology Approach, Timing and Strategies. J. Clin. Med. 2023, 12, 260. https://doi.org/10.3390/jcm12010260

VITAL Objectives and Phases

H1

BIOLOGICAL TECHNOLOGIES OFFICE

Explore High-Fidelity Models; Foundation for Real-Time Reduced Order Models

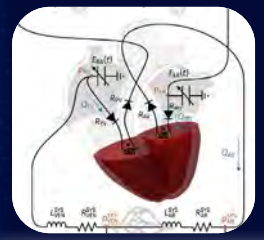
1. Learn High Fidelity Digital Twin Performance Envelopes

High Fidelity Cardiovascular Model

- *Physics-faithful*
- *Measurement-informed*
- *Multi-scale*
- *Personalized*
- *Predictive*

2. HF → ROM Tradeoffs for Real-time Responsiveness

Real-Time Reduced Order Model



- *HF-faithful*
- *Continuous sensing*
- *Essential dynamics*
- *Reduced compute*

Integrated Validation

Model

Physiological State Estimation

+

Intrinsic Uncertainty Quantification

Validation progression including but not limited to:

in silico	Phantoms	Baseline fidelity	Noninvasive physiological perturbation	Preclinical benchmark in established translational models

Image-to-Physics-to-Twin Construction Pipeline

HF – High Fidelity
ROM – Reduced Order Model

VITAL Technical Approach

H3

BIOLOGICAL TECHNOLOGIES OFFICE

Multi-modal Measurement

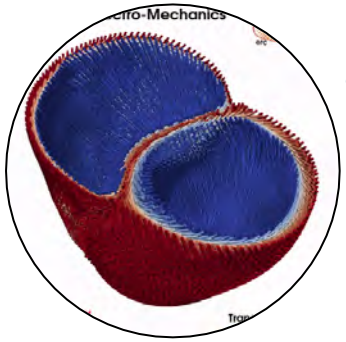
- Information-dense fieldable sensors that detect early signs of decomposition

- Multi-sensor fusion supports system-level modeling
- Multi-signal fusion and analysis at each site
- Fused data supports *in situ* model updates in the field

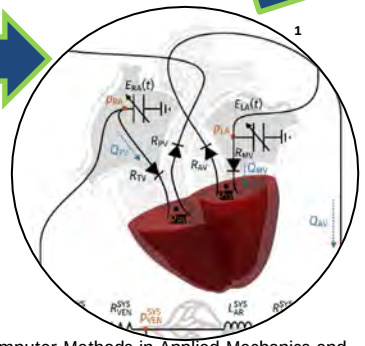
Imaging, Chemical Sensing SBP, SPO2, EKG Waveform Analysis

Reduced Order Modeling

- Fieldable, physics-faithful Digital Twins (DTs) capable of real-time prediction



- High Fidelity (HF) Models transformed into Reduced Order Models (ROMs)
- Sensor-informed personalized DTs in the field



[1]Piersanti, Roberto, et al. Computer Methods in Applied Mechanics and Engineering 391 (2022): 114607.

Decision Support

- Model-informed skill-aware forward simulation to predict intervention outcomes
- Predict how the patient's condition will worsen using a virtual model
- Simulate treatments on the virtual model to find the best option
- Act decisively with the optimal intervention

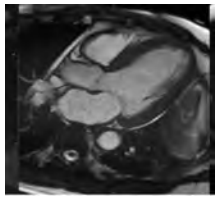
VITAL will innovate and integrate real-time data, models, and decision support

TBI: Traumatic Brain Injury [1]iHeart,

High Fidelity Model Construction

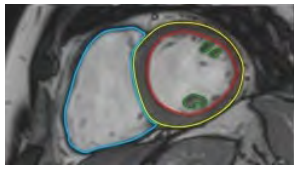
Patient Specific Data

High-resolution CT/MR, 4D-flow MRI/doppler



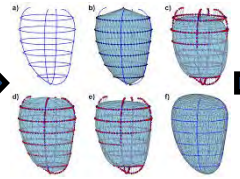
Automated Geometry Construction

Segmentation, anatomic labeling



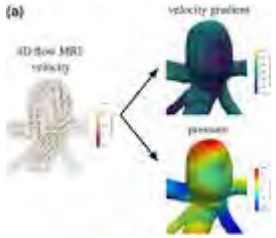
High Quality Meshing

Boundary layer meshes for CFD, myocardium, vessel walls



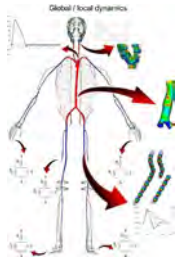
Muti-physics Solvers

Navier-Stokes CFD, FSI



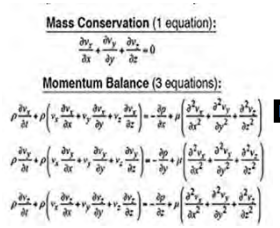
Physiologic Coupling Across Scales (if needed)

3D <-> 1D/0D coupling w/ proper boundary conditions



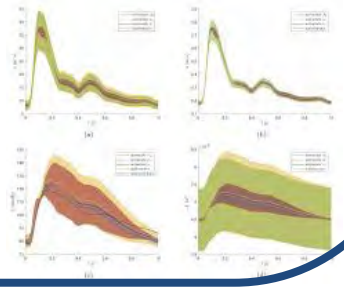
Parameter Personalization

Inverse methods for parameter fitting (compliance, stiffness, contractibility)



Uncertainty Quantification

Calibration, sensitivity/identifiability, safety bounds



Sensor-Coupled ROM Construction

HF $\dot{x} = f(x, u, \mu), \qquad y = h(x) + \eta$

$x(t)$: full HF state vector
$f(.)$: physics-time evolution operator
$u(t)$: inputs/controls/interventions
$\mu(t)$: fixed or slowly varying parameter
$y(t)$: measured signal
$h(.)$: measurement operator
$\eta(t)$: measurement noise

ROM $x \approx Va, \qquad a = g(a, \hat{u}, \theta), \qquad \hat{y} = h(Va)$

V : reduced basis
$x \approx Va$: state approximation
$a(t)$: ROM coordinates/reduced space
$g(.)$: reduced physics-time evolution operator
$\hat{u}$: ROM inputs/controls/interventions
θ : ROM parameters
$\hat{y}(t)$: ROM predicted sensor output

CFD: Computational Fluid Dynamics
CT: Computed Tomography
FSI: Fluid-Structure Interaction
HF: High Fidelity
MRI: Magnetic Resonance Imaging
ROM: Reduced Order Model

Physiology-faithful HF. HF-faithful ROM — only as detailed as the mission demands.

Dual Mapping

Measurement refinement

$$\textbf{(physiology + disorder + interventions)} \implies \textbf{(what sensors should see / key fields)}$$

It learns:

$$\mathcal{G}\colon (\boldsymbol{\theta},\ \boldsymbol{u(t)},\ \textbf{context}) \mapsto \hat{\boldsymbol{y}}(\boldsymbol{t})$$

θ: Latent parameters/state (bleed rate, vascular tone, obstruction severity, effective circulating volume, etc.)
$u(t)$: Interventions/inputs (tourniquet, transfuse, ventilate, decompress, warming)
$\hat{y}(t)$: predicted sensor waveforms/features (carotid pressure, Doppler flow features, PPG morphology, impedance)

Inverse mapping

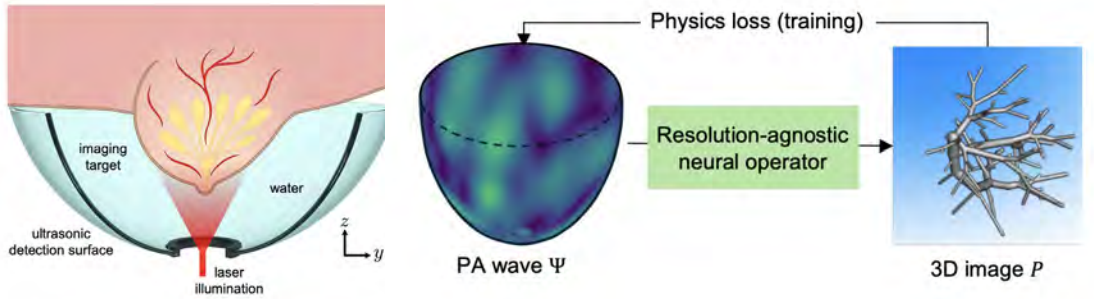
Sensor measurements (carotid waveform/Doppler/PPG/impedance)
→
Latent physiologic state/parameters (bleed rate, venous return, tone, perfusion reserve, obstruction severity).

$$\boldsymbol{y(t)} \mapsto \textbf{latent state } (\boldsymbol{a(t)}, \boldsymbol{\theta})$$

$a(t)$: ROM coordinates/reduced states

Surrogate Modeling with AI

Example: input field $a(\mathbf{x})$ ⟶ output field $u(\mathbf{x})$)



3D photoacoustic imaging is an inverse wave problem
Classic solvers: approximate physics inversion + denoising

Wang, Jiayun, et al. "Accelerating 3D Photoacoustic Computed Tomography with End-to-End Physics-Aware Neural Operators." arXiv preprint arXiv:2509.09894 (2025).

- ❑ **Faithful to the Physics**: “Scientifically valid" predictions
- ❑ **Function-Level Generalization**: Generalize to new scenarios by learning mappings between entire functions, not just data points.
- ❑ **Efficiently Updatable**: Model's ability to update with scarce new data.
- ❑ **Built-in Uncertainty Quantification**: Assess confidence, provide a crucial measure of reliability for every prediction and intervention.

FNO: Fourier Neural Operator
PINO: Physics-Informed Neural Operator
PDE: Partial Differential Equation
PPG: Photoplethysmogram
ROM: Reduced Order Model

We will learn the physics map for info-dense sensors and ROMs

What This Program Is & Isn't

BIOLOGICAL TECHNOLOGIES OFFICE

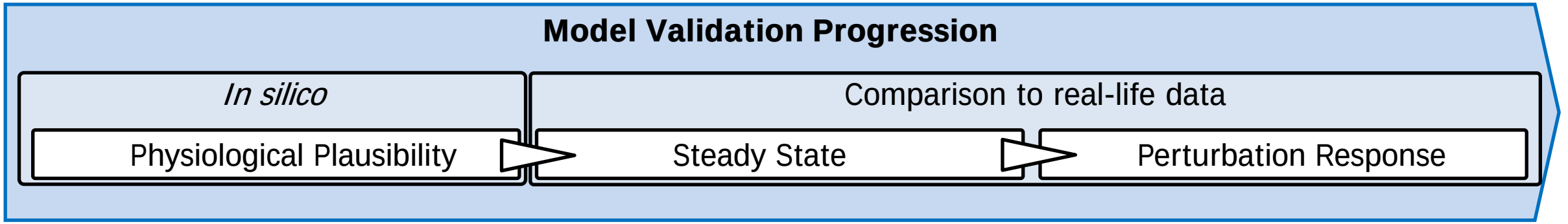
What this program IS doing:	What this Program is NOT doing:
This is a "Learn" program. *The program will focus on construction of models.* *VITAL learns how to create acute and chronic disorder reduced-order models from high-fidelity models that integrate seamlessly with real-time measurement models.* Development of this technology is enabled by: • Mechanistic AI as a proxy for ROMs that remain faithful to the physics of HF models. Leverage HF model as the mothership. • Incorporating intervention paradigms into ROMs.	• Construction of ROM for a single disorder condition in an *ad hoc* fashion *This already exists but lacks scale/coverage.* • Sole focus on construction of high-fidelity models based on hospital data/images *These already exist in a limited capacity. The problem is the lack of update after patient leaves the hospital (digital cousin at best).* • Create a new advanced sensor for ROM or UI *May be a follow-up program.*

AI: Artificial Intelligence
HF: High Fidelity
ROM: Reduced Order Model
UI: User Interface

Areas Out of Scope

- Digital Twins addressing anything other than the cardiovascular system
- Conditions other than:
  - Acute models: Hemorrhagic shock
  - Chronic models: Heart failure
- Model construction approaches not explicitly data-driven or that lack a direct lineage to physiological measurements.
- Models not grounded in observable dynamics or based on purely theoretical constructs without a direct data-driven lineage.
- Developing a ROM as a standalone effort without first establishing and validating it against a corresponding HF parent model. The entire HF-to-ROM pipeline is a required component.
- The development of novel imaging techniques, new types of biological sensors, or data acquisition hardware. The program is focused on the computational modeling pipeline that uses the output of such sensors.
- Purely data-driven "black box" machine learning models (e.g., standard deep learning networks) that predict outcomes without an embedded, verifiable physical or biological mechanism.

Validation Methodology



"Does the model obey physiological theory and maintain homeostasis?"

- Conserves mass/energy, exhibits a stable heartbeat, and reaches equilibrium
- Verification focuses on numerical stability, conservation, and physiological plausibility

"Does the model reproduce steady-state physiology of a biological instance (human or animal)?"

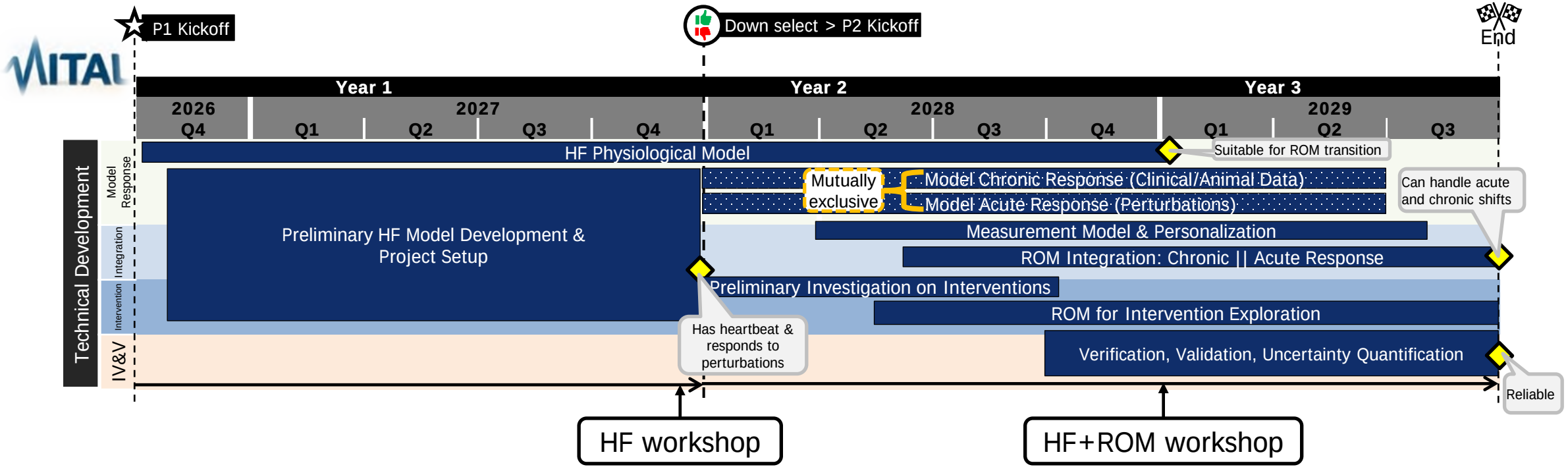
- Experimental human or animal data used to assess baseline pressures, flows, volumes, and rhythms
- Validation focuses on agreement with observed resting physiology

"Does the model correctly reproduce responses to acute and chronic perturbations?"

- Acute and chronic responses are assessed through perturbations
- Validation focuses on response direction, magnitude, timing, and recovery dynamics

Measuring the capability limits of the models is a core goal of the program

VITAL Program Structure



Baseline (Threshold of Usability) Metrics

Category	Measurement Methodology	Quantitative Metric
Numerical Credibility (Gate)	Stability, conservation, and repeatability of the HF model	• ≤2% cumulative mass/momentum drift over 30–60 min (simulated time) • Stable under ±30% parameter perturbation • Relative standard deviation (SD/mean) of outputs ≤10%
Uncertainty Quantification	Calibration and credibility of predictive uncertainty	• Existence of confidence bounds on all outputs • Expected Calibration Error (ECE) ≤0.15
Perturbation Fidelity	Physiological correctness of response to controlled perturbations	• ≥95% correct directionality • Response magnitude within ±25% of reference • Latency error ≤20%

Capability Goals

Category	Definition	Desired Performance
Sensitivity & Robustness	Dependence on parameters, segmentation, and data sparsity	• ≤25% performance degradation for < ±3 voxel segmentation error • ≥70% variance explained by top parameters

Baseline (Threshold of Usability) Metrics

Metric	Measurement Methodology	Value
HF-to-ROM Fidelity Retention	Preservation of HF behavior after reduction	• ≤15% degradation relative to refined HF baseline • No non-physiological artifacts
Continuous Update Capability	Real-time state and parameter updating	• End-to-end update latency ≤5 s • Stable streaming assimilation
Prediction Horizon	Predicting event at time t before it occurs with AUROC ≥80%	• Hemorrhagic shock t ≥15 minutes • Heart failure Stage 4, t ≥ 80% * ($t_{onset\text{-}stage\ 4}$ - $t_{onset\text{-}stage\ 3}$)[1]
Intervention Response Prediction	Prediction of physiological response to treatment	• ≥50% faster time-to-intervention • ≥90% expert concordance • ≥10X richer expert reasoning • ≥50% improvement in maintaining survivable physiological windows

[1] To enhance model accuracy, performers are advised to leverage quantifiable metrics to characterize heart failure stages, such as: End-systolic elastance (Ees), Ventricular-Arterial Coupling (Ea/Ees), Effective Arterial Elastance (Ea), Natriuretic peptide levels (BNP and NT-proBNP) or Echocardiographic measurements (e.g., LVEF)

Capability Goals

Benchmark	Definition	Desired Performance
HF Envelope Expansion	Improvement of HF predictive capability beyond Phase 1	≥30% increase in predictive horizon or reduction in uncertainty vs Phase 1 baseline
HF Perturbation Generalization	HF accuracy across expanded acute–chronic perturbations	≤20% error across mixed stress states (e.g., hemorrhage + vasoactive + hypothermia)
HF Uncertainty Reduction	Improved calibration through additional data and refinement	Expected Calibration Error (ECE) ≤0.10 for HF models
HF Numerical Robustness	Stability under broader operating conditions	Stable under ±40% parameter variation and ≥2× longer simulations
Robustness & Graceful Degradation	Behavior under missing/noisy data	• ≤15% performance loss with ≥40% data dropout • Safe deferral to standard practice defined under Clinical Practice Guidelines (CPG)
Uncertainty-Aware Decision Logic	Use of uncertainty to gate predictions	• Expected Calibration Error (ECE) ≤0.05 • Explicit uncertainty-triggered deferral
Computational Efficiency	Speedup relative to refined HF models	≥1,000× runtime improvement
Out-of-Distribution (OOD) Detection & Failure Reporting	Detection of unseen or invalid regimes	• ≥90% OOD detection • Documented fallback behavior

VITAL Milestones/Deliverables

H8

BIOLOGICAL TECHNOLOGIES OFFICE

	Number	Month	Milestone	Deliverable
Phase 1	1	1	Phase 1 Kickoff meeting	Briefing slides that are acceptable to DARPA.
	2	4	Regulatory approval received for human and/or animal subjects	Copy of approval document(s)
	3	9	Design of initial HF model, including development and implementation plans	Report on status of initial HF model and roadmap to achieve the Phase 1 metrics
	4	12	Implementation of initial HF model with demonstrable outputs achieved	Performance demonstration of initial HF model; report on metrics achieved, observed limitations of the model, and paths to improve performance
	5	15	End of Phase 1	Presentation of HF model capabilities and limitations at scheduled workshop to invited subject matter experts from the DoW and industrial stakeholder communities
Phase 2	6	16	Phase 2 Kickoff meeting	Briefing slides that are acceptable to DARPA.
	7	24	Preliminary results available for initial investigations of interventions; Initial models of acute or chronic responses developed; Measurement models and personalization development initiated	Report on preliminary results of initial studies of ROM behavior for interventions and responses to acute and chronic perturbations and plan forward for next steps
	8	30	HF physiological model fully developed for integration; investigation on interventions completed; progress on acute or chronic response models per plan; initial ROM integration with HF ready for demonstration	Report on continuous updating capability of the integrated HF/ROM; ability to anticipate adverse trajectories; and prediction of responses to interventions
	9	32	Assessment of capabilities and limitations completed; ROM integration substantially completed	Presentation of integrated HF/ROM capabilities and limitations at scheduled workshop to invited subject matter experts from the DoW and industrial stakeholder communities
	10	36	End of Phase 2; ROM integration and VVUQ completed	End of program review; Final report including final conclusions of all prior tasks; HF/ROM integration; and verification, validation, and uncertainty quantification (VVUQ)

VITAL Schedule

Month	Deliverable
Phase 1	
1	Kickoff meeting (in-person)
3	Quarterly program review (virtual)
6	Quarterly program review (virtual)
9	Quarterly program review (virtual)
	First report on High Fidelity model plausibility due (final date)
12	Quarterly program review (virtual)
15	Demonstration of initial HF model (final date)
	HF model workshop (in-person)
Phase 2	
16	Kickoff meeting (in-person)
18	Quarterly program review (virtual)
21	Quarterly program review (virtual)
24	Quarterly program review (virtual or at performer site, at DARPA's discretion)
	Report on results of initial HF/ROM integration (final date)
27	Quarterly program review (virtual)
30	HF+ROM model workshop (in-person)
	Report on continuous updating capability of the integrated HF/ROM due (final date)
33	Quarterly program review (virtual)
36	End of program review (in-person); Final report due

VITAL Strategic Advisory Committee

Mission: To provide continuous, mission-driven oversight to ensure technical excellence, stakeholder alignment, and successful real-world deployment.

Advisor Category	Core Contribution
DoW Stakeholders	Ensures focus on warfighter needs and enable additional engagement with DoW/US Government.
Industry Veterans	Advises on at-scale implementation and technical feasibility.
Regulatory Experts	Explore complex validation and accreditation pathways.
Proven Entrepreneurs	Guides the strategy for rapid and sustainable technology transition.

VITAL Government-led Evaluation

An independent T&E team will define test cases for each protocol and curate the performer-contributed data for performance assessment.

Phase 1	Phase 2	T&E responsibilities
Evaluate HF models	HF-to-ROM integration	Assess agreement with measured trajectories and response dynamics
		Ask for additional test cases and/or perturbations
		Analyze the results of the performers
		Define additional composite stress scenarios to expose failure points

VITAL Broader Impacts

BIOLOGICAL TECHNOLOGIES OFFICE

Impact Objective: Deliver decision-grade digital twins for combat casualty care that improve survival and accelerate care

DoW Impact 1: Save Warfighter Lives

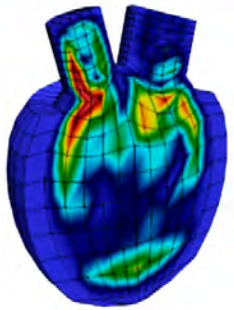
- Shift skills & intervention to where most deaths occur (POI to Role 2)
- Support reverse & situational triage

DoW Impact 2: Enable Intelligent Logistics

- Predictive logistics will optimize limited resources
- Shift from gambling to prediction

DoW Impact 3: Data Factories

- Transform digital twins into simulation-driven data factories, reducing reliance on costly experiments and accelerate development of medical technologies



Broader Stakeholders

- Role 2 surgical and resuscitation teams
- Command and evacuation planners
- Civilian and disaster-response medicine
- Chronic cardiovascular disorders due to PTSD and other combat related injuries
- Training and simulation

Cardiovascular diseases causes 1 in 4 US Deaths. Stroke and heart failure are major cost drivers. 10% fewer HF admissions ($7B/year) and 5% better stroke outcomes/triage ($2B/year)

HF: Healthcare Facility
POI: Point Of Injury
PTSD: Post-Traumatic Stress Disorder

Frequently Asked Questions (FAQs)

- Please **submit all your questions** about program details via **VITAL Program E-mail (VITAL@darpa.mil)**. The team will compile, and we'll hold a discussion session at the end of the day and run through them then.

- We will make every effort to answer your questions quickly. All questions (as determined appropriate) will be addressed in the **FAQ on the opportunity website**.