Variable Vector Countermeasure Suit (V2Suit) for Space Habitation and Exploration

NASA Innovative Advanced Concepts Phase II

Kevin R. Duda, Ph.D.
The Charles Stark Draper Laboratory, Inc.

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V2Suit for Space Habitation and Exploration

- Spaceflight adaptation countermeasure suit
  - Sensorimotor
  - Musculoskeletal

- Utilizes properties of gyroscopes to provide “viscous resistance” during movement
V2Suit Motivation

- No “down” in 0-G
  - Visual perceptions dominate
  - “Down” direction may change

- Physiological adaptation to weightlessness

- Perceptual and resistance benefits:
  - Sensorimotor adaptation
    - Earth G, Moon G, Mars G
  - Musculoskeletal de-conditioning

The V2Suit facilitates human adaptation and performance during long-duration spaceflight


V2Suit Phase I Summary

- **Human-System Integration**
  - Module form factor and placement
  - Interface with body/garment

- **Initial V2Suit Module Design**
  - Modeling and simulation
  - Flywheel orientation and placement
  - Integration and packaging

- **Technology R&D**
  - Alternate uses
  - Technology assessment
  - Key enabling technologies
V2Suit Phase I

Lifesize Mannequin

Upper Arm Module

Lower Arm Module

Power & Processing

Material:
Stainless steel,
\( \rho = 7950 \text{ kg/m}^3 \)
\( m = 0.0576 \text{ kg} \)
\( I_x = 1.0443 \times 10^{-5} \text{ kg*m}^2 \)
\( r = 0.01905 \text{ m} \)
(0.75 in.)
\( h = 0.00635 \text{ m} \)
(0.25 in.)

2-Axis CMG Torque

O1 O2 O3 O4 O5 O6 O7 O8 O9 O10 O11 O12

Gimbal Rate [rad/sec]

Spin Rate [rad/sec]

Torque Magnitude [N-m]

V2Suit Module

IMU
CMGs
Motor controllers

• IMU data
• Flywheel spin rate
• Flywheel gimbal rate

V2Suit Module Orientation

Power

Parameterized “Down” Tracking

Resistance Magnitude

Motor Commands

Central Processing and Commanding

Initialization

Navigation

Actuation

Prototype built from RC aircraft/helicopter components to demonstrate concept and develop technology roadmap
Body movements add to the CMG gimbal vector and if not accounted for, produce undesirable torques.

\[ \vec{\tau} = -\vec{\omega} \times \vec{h} \]

Gimbal Movement, Body Movement
**Gimballed, spinning mass**

\[ \omega_g = \omega \]

\[ \omega_s = h \]

Coordinated actuation to maintain gyroscopic torque along module y-axis results in undesirable perturbations due to body movement.
V2Suit Phase I – Modeling & Simulation

- **Fixed Gimbal Rate**
  - 5 rad/sec

- **Coordinated Spin Rate**
  - 10-100 rad/sec

Coordinated actuation to maintain gyroscopic torque along module y-axis and reject undesirable perturbations – **demonstrating V2Suit proof of concept**
V2Suit Phase II Plans
V2Suit Phase II Research Aims

- **Aim 1: Mission Definition & Assessment**
  - Define use cases
  - Operational requirements
  - Performance Metrics

- **Aim 2: Key Technology Determination and Feasibility**
  - Integration of COTS components
  - Advancements in algorithms, sensors, packaging, and power

Prototype built from RC aircraft/helicopter components to demonstrate concept and develop technology roadmap.
V2Suit Phase II Research Aims

- **Aim 3: Integrated V2Suit Simulation and Performance Assessment**
  - Simulation architecture
  - Model development
  - Closed-Loop Performance Analysis

- **Aim 4: V2Suit Module Integration and Evaluation**
  - CAD Modeling
  - Human-System Interface
  - Technology Selection & Integration
  - Performance Analysis
V2Suit Demonstration and Technology Roadmap

**Phase I**
- V2Suit Phase II
  - Modeling & Sim
  - Module Integration
  - Tech Assessment

**Tech R&D**
- Packaging, HSI
- Electrical, Comm
- Algs & Software
- Space Hardware

**Flight Test System**
- Fully integrated system
- Flight hardware and software
- V2Suit system-level countermeasure integration

**Operations**
- Spaceflight demo

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**Technology Readiness**
- Proof of Concept
- Brassboard
- Engineering Unit
- Mission Config
- Operational Unit

**Demonstration Milestones**
- Concept evaluation
- Limited user evaluations
- Lab testing
- Frictionless testing
- Parabolic flights
- ISS Expeditions
- Space Exploration

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**Algorithms**
- V2Suit module position, velocity, orientation
- CMG control algorithms

**Packaging**
- Currently available COTS motors, slip rings
- Ultra miniature, high torque motors
- Miniature high speed slip rings

**Sensing**
- MEMS IMUs
- Optical motion tracking
- Robust Vision-Aided Navigation (with miniaturized sensors)

**Power**
- High-density miniature batteries
- Wireless power
V2Suit Phase II Progress

- “Down” Tracking
  - Initialization parameter
  - Track V2Suit module orientation during movements
  - Command CMGs

![Diagram of V2Suit Phase II Progress](image)

**Defination of Coordinate Frames**

- Inertial
- Body
- Module

**Parameterized “Down” Tracking**

**Central Processing and Commanding**

- V2Suit Modules
  - IMUs
  - Flywheels
  - Motor controllers

- V2Suit Module Orientation
  - Parameterized “Down” Tracking

- V2Suit Module Pos., Vel.

- Resistance Magnitude

- Power

- Motor Commands

- Navigation

- Initialization

- Actuation
V2Suit Phase II Progress

- Defined Rotation Matrices
  - Track inertial “down”
  - Each V2Suit module
  - Regardless of body orientation

![Diagram showing rotation matrices and arm movement](image)
Variable Vector Countermeasure Suit (V2Suit) for Space Habitation and Exploration

THE V2SUIT CONCEPT
The V2Suit is a spaceflight physiological adaptation countermeasure platform using gyroscopic motion to provide “viscous resistance” during movements.

APPROACH
Four integrated aims to further the V2Suit concept development – a goal of operational demonstration

- Aim 1: V2Suit mission assessment
- Aim 2: Technology assessment and roadmap
- Aim 3: System-level closed-loop simulation
- Aim 4: V2Suit module design and integration

Start TRL: 2          End TRL: 4 (early)

AEROSPACE IMPACT
SPACE TECHNOLOGY WITH EARTH APPLICATIONS

An integrated and comprehensive countermeasure system has a measurable impact:
- Save 2.5 hours per day in allocated exercise time
- Exercise equipment mass and volume
- Enable optimal performance during mission-specific gravitational transitions (landing, egress)

The V2Suit is an enabler for space exploration mission technologies, including human adaptation and countermeasures, health monitoring, robotic interfaces, and adaptation and operations during artificial gravity.

KEY ENABLING TECHNOLOGIES

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<th>Packaging</th>
<th>Sensing</th>
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<td>Inertial tracking of position, velocity, orientation</td>
<td>Ultra-miniature high torque motors</td>
<td>MEMS inertial measurement units</td>
<td>High-density miniaturized batteries</td>
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<td>Control moment gyroscope control</td>
<td>Miniaturized components, dense packaging</td>
<td>Robust vision-aided navigation</td>
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Technologies for a robust, operational system