# 有人宇宙システム開発と大学における研究

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## 内容

- ICES 2010報告
- COSPAR 2010 F4報告
- 私の発表報告
- MIT Strategic Engineeringの研究紹介
- Logistics Network運用アルゴリズム開発におけるMindstormsの利用

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## ICES 2010概観

- **毎年、北米もしくはヨーロッパで開催される環境システムの国際会議**
- **発表論文数：313件**
- **日本からの発表論文数：19件**
- **参加者数：313人（開催日3日目夕方発表）**
- **パネルディスカッション**
  - Challenges ECLSS for Long-Duration Missions Out of LEO
    - Michael Ewert, NASA JSC
    - Robert M. Bagdigian, NASA MSC
    - Tim Nalette, Hamilton Sundstrand
    - Christophe Lasseur, ESA
    - Grant Anderson, Paragon
    - Masato Sakurai, JAXA
- **ポスターセッション**
  - 初めて日本からの学生参加者あり

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## 国際環境システム会議(ICES 2010)発表件数

| Code | Session | Number |
|---|---|---|
| ICES100 | Environmental and Thermal Control of Space Exploration Vehicles | 0 |
| ICES101 | Spacecraft and Instrument Thermal Design, Testing and Technology A, B, C | 12 |
| ICES102 | Thermal Control for Planetary Surface Missions and Systems A, B | 6 |
| ICES103 | Thermal and EnvironmentalControl of Crewed Lunar Exploration Vehicles A, B, C, D | 16 |
| ICES106 | Space Station and Manned Orbiting Infrastructures Thermal Control A, B, C | 5 |
| ICES107 | Thermal and Environmental Control Engineering Analysis and Software A, B, C, D | 12 |
| ICES108 | Advances in Thermal Control Technology A, B, C | 8 |
| ICES109 | Space Structures for Exploration | 3 |
| ICES200 | Physico-Chemical Processes: Air and Water A, B, C | 8 |
| ICES201 | Two-Phase Thermal Control Technology A, B, C, D, E | 12 |
| ICES202 | Satellite, Payload, and Instrument Thermal Control A, B, C | 8 |
| ICES203 | Thermal Testing A, B, C | 10 |
| ICES204 | Bioregenerative Life Support A, B, C | 7 |
| ICES205 | Advanced Life Support Sensor and Control Technology A, B, C | 10 |
| ICES300 | ECLSS.Environmental Control and Life Support Systems. Modeling and Test Correlation A, B, C | 8 |
| ICES301 | Advanced Life Support Systems Control | 3 |
| ICES302 | Physio-Chemical Life Support Process Development A, B, C, D, E, F, G | 24 |
| ICES304 | Development for Space Missions and Terrestrial Applications | 2 |
| ICES307 | Environmental and Thermal Control for Commercial Crewed and Cargo Transport Spacecraft | 5 |
| ICES308 | CEV ECLSS and Thermal Control A, B | 5 |
| ICES309 | Education Outreach A, B, C | 6 |
| ICES400 | Extravehicular Activity: Space Suits A, B, C, D, E, F | 14 |
| ICES401 | Extravehicular Activity: Systems | 3 |
| ICES402 | Extravehicular Activity: PLSS and Support Equipment A, B, C, D | 11 |
| ICES403 | Extravehicular Activity: Operations | 2 |
| ICES404 | International Space Station ECLS: Systems A, B, C, D | 7 |
| ICES405 | International Space Station ECLS: Air and Water Systems A, B | 7 |
| ICES406 | Human/Robotics System Interaction | 2 |
| ICES407 | Spacecraft Water/Air Quality: Maintenance and Monitoring A, B | 6 |
| ICES408 | Regenerable Life Support Processes and Systems A, B | 5 |
| ICES409 | Microbial Factors Applied to Design A, B | 4 |
| ICES410 | Airliner Cabin Air: Monitoring, Control, Environmental Health, and Comfort Issues A, B | 5 |
| ICES502 | Life Support Systems Engineering and Analysis A, B | 3 |
| ICES503 | Space Architecture A, B, C, D, E, F, G | 18 |
| ICES504 | Radiation Issues for Space Flight A, B | 7 |
| ICES505 | Management of Air Quality in Sealed Environments A, B | 6 |
| ICES509 | Lunar Life Support A, B | 7 |
| ICES510 | Human Factors for Space Missions Ground and Flight Operations A, B, C, D | 7 |
| ICES511 | Mars and Beyond | 3 |
| ICES513 | Fire Safety in Spacecraft and Enclosed Habitats A, B | 8 |
| ICES514 | Lunar and Martian Dust Properties and Mitigation Technologies A, B, C, D, E | 12 |
| ICES515 | Mission Assurance and Reliability Techniques for Environmental Systems A, B | 6 |
| ICES700 | Student Poster Competition | ? |

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## 興味を持った発表

- **ICES301 Advanced Life Support Systems Control**
  - An operations Management Method for a Logistics Network of Distributed Life Support Systems on the Lunar Surface
  - Autonomous Control Method for Material Circulation in Advanced Life Support System
  - Reak-Time Monitoring of ECLSS Flight Rules
- **ICES502 Life Support Systems Engineering and Analysis**
  - Using Radar Charts to Select Life Support Technology
  - The Virtual Habitat – A Tool for Dynamic Life Support System Simulations
  - Study Status of the ECLSS for Next Manned Space Mission in JAXA
- **ICES503 Space Architecture**
  - The "Tesla" Orbital Space Settlement
- **ICES509 Lunar Life Support**
  - Exploration Life Support Critical Questions for Future Human Space Missions
  - Lunar Outpost Life Support Architecture Study Based on a High-Mobility Exploration Scenario
  - Life Support with Failures and Variable Supply
  - An Environmental Control and Life Support System Concept for a Pressurized Lunar Rover
- **ICES309 Education Outreach**
  - Constellation Program Design Challenges as Opportunities for Education Outreach and Workforce Development for Senior Design Classes
- **ICES404 International Space Station ECLS: Systems**
  - International Space Station Environmental Control and Life Support System Status: 2009-2010
  - Environmental Control and Life Support System Integration Strategy for six Crew Operation

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## COSPAR 2010 F4

- F Life Sciences as Related to Space
  - F4 Natural and Artificial Ecosystems
    - F41 Closed Ecological Systems for Earth and Space
    - F42 Advanced Life Support Systems and Facilities
    - F43 Mathematical and Computer Simulation of CELSS
    - F44 Influence of Spaceflight Environments on Biological Systems
    - F45 Closure as a Specific Property of Manmade Ecosystems and Biospheres
    - F46 Genomic, Proteomic and Metabolic Changes of Biosystems in Spaceflight Environment
    - F47 Innovative Approaches to Space Agriculture
    - F48 Sustainable Systems for Life Support and Space Exploration through ISRU (in-situ resource utilization) and New Technologies

## COSPAR 2010 F4概観

- 生命維持システム関連の研究者が多く参加するセッション
  - F41 Closed Ecological Systems for Earth and Space
  - F42 Advanced Life Support Systems and Facilities
  - F43 Mathematical and Computer Simulation of CELSS
- 日本からの参加者が多かったセッション
  - F47 Innovative Approaches to Space Agriculture
- 主だった話題
  - F41ではBIOS4について言及した発表があった
  - F43セッション参加国は、ICESの参加国（欧米）＋ロシア、中国
  - 中国では小規模な閉鎖実験（人、植物、かいこなど）が開始されている（北京航空航天大学）。それと同時にMatlab/Simulinkを利用したシミュレーションも行われている。

## COSPAR 2010 F43発表

| No. | Title | Author | Status | Duration | Solicited |
|---|---|---|---|---|---|
| **Half Day Session:**<br>**Subtitle:** 1<br>**Date:** Wednesday, 21 July 2010, 14:30 - 16:00<br>**Room:** Hall 4.1 / Uranus<br>**Chair:** Dawei Hu | | | | | |
| 1 | Mathematical modelling of soil respiration and carbon accumulation dynamics in soils of CELSS | Sergey Bartsev | ACCEPTED | 14:30-14:50<br>20 min | yes |
| 2 | Mathematical modeling of the “plant community – soil-like substrate – gas exchange with the human” closed ecosystem | Yuri Barkhatov | ACCEPTED | 14:50-15:05<br>15 min | no |
| 3 | Carbon dioxide dynamics in an artificial ecosystem | Enzhu Hu | ACCEPTED | 15:05-15:25<br>20 min | yes |
| 4 | Virtual Habitat – a dynamic simulation of closed life support systems – human model status | Markus Czupalla | ACCEPTED | 15:25-15:40<br>15 min | no |
| 5 | Dependence of CELSS model stability on the properties of metabolism of composing organisms | Sergey Bartsev | ACCEPTED | 15:40-15:55<br>15 min | no |
| **Break**<br>**Subtitle:** 2<br>**Date:** Wednesday, 21 July 2010, 17:30 - 19:00<br>**Room:** Hall 4.1 / Uranus<br>**Chair:** Sergey Bartsev | | | | | |
| 6 | Design of a Regenerative Life Support System for a Moon Base. Preliminary Results. | Jordi Duatis Juarez | ACCEPTED | 17:30-17:45<br>15 min | no |
| 7 | Design and construction of miniature artificial ecosystem based on dynamic response optimization | Dawei Hu | ACCEPTED | 17:45-18:00<br>15 min | yes |
| 8 | Preliminary Modelling of Mass Flux at the Surface of Plant Leaves within the MELiSSA Higher Plant Compartments | Madeleine Holmberg | ACCEPTED | 18:00-18:15<br>15 min | no |
| 9 | Simulation Studies on Harnessing of Artificial Ecosystems in Space Colonies | Hiroyuki Miyajima | ACCEPTED | 18:15-18:30<br>15 min | no |
| 10 | Artificial Closed Ecosystems Stability and Human Control Limitations | Vadim Rygalov | ACCEPTED | 18:30-18:45<br>15 min | yes |
| 11 | Alisse : Advanced life support system evaluator | Jean Brunet | ACCEPTED | 18:45-19:00<br>15 min | no |

## 私の発表

- ICES 2010
  - セッション
    - Advanced Life Support Control
  - タイトル
    - An Operations Management Method for a Logistics Network of Distributed Life Support Systems on the Lunar Surface
- COSPAR 2010
  - セッション
    - Mathematical and Computer Simulation of CELSS
  - タイトル
    - Simulation Studies of the Harnessing of Artificial Ecosystems in Space Colonies

## まとめ

- 設計や制御に関する研究のコミュニティが小さくなっている？
- ICESだけではなくCOSPARにも参加することで、ロシア、中国の動向をつかめる
- 1つの大学の事例ではあるが、2年前のモントリオールでの発表に比べ、中国の研究は格段に進んでいる
- 私の研究について
  - スペースコロニーの研究は突拍子もないもの？
  - インドの発表事例、会場の冷ややかな反応
  - 私の失敗
  - 計算結果の検証
- ICESは開発に比重をおいた発表が多い、COSPARは研究に比重をおいた発表が多い？
- 研究グループによりプロジェクトに取り組んでいる。
  - MELiSSA Project, 中国の例
  - 研究機関、企業、大学の役割、NASAとESAの違い
- シミュレーションと実験を組み合わせた研究が主流？
  - Analog siteによるフィールドテスト

## 事例1　MIT Strategic Engineering

- MIT Strategic Engineering, Professor Olivier L. de Weck.
- Strategic Engineeringは複雑なシステムや製品を建築したり設計したりするための方法である。Strategic Engineeringはライフサイクルコストを最大化しながらlock-inの効果を最小化するために将来の不確定性や状況を慎重に説明する。
- 対象分野
  - Design for Changeability
  - Product Platforms and Commonality
  - Interplanetary Space Logistics
- 補助的な分野
  - Systems Architecture and Engineering
  - Multidisciplinary Design Optimization
  - Integrated Modeling and Simulation

## 対象分野

- Design for Changeability (DfC)
  - 複雑なシステムや製品を時間によってどのように変化させるか、どのようにその可変性を設計するのか。
    - 可変性とは、複雑さやコストの大幅な増加を伴わないで、システムがその形態の中で改良を実施できる程度を意味する。柔軟なシステムは高い可変性を有している。簡単に変えることができないシステムはlock-inに悩まされる。
- Product Platforms and Commonality
  - 産業界での実践を通して製品開発の基盤化、共通化、標準化のフレームワークや手法を開発
- Interplanetary Space Logistics
  - 効率的な宇宙探査や運用を可能にすることを目的としている。1回のミッションではなく、人間やロボットによるミッションがどのようにもっと持続的に行われるかを検討する。
  - 地上での運用、打ち上げ、宇宙での運用、降下と着陸、惑星表面での運用を通して、ビークル、乗員、着陸後の補給の流れ、地上での製造・改修を含むモデル化、計画、シミュレーション、最適化

# 特定の方法など

- **Design for Changeability (DfC)**
  - Change Propagation Analysis
  - Staged Deployment Strategy for Complex Systems (e.g. Satellite Constellations)
  - Flexible Product Platform Development Process
  - Theory of Reconfigurability in System Design
  - Technology Infusion Analysis
  - Time-Expanded Decision Networks (TDN)
- **Product Platforms and Commonality**
  - First comprehensive solution of the product platform extent problem
  - Quantifying the impact of commonality on spare parts logistics
  - A seven-step process for flowing exogenous market and demand uncertainties into a product platform to identify opportunities for flexibility (real options)
  - The sensitivity-DSM (sDSM) and Invariant Design-Rules (IDR) method, for isolating subsystems that are insensitive to external requirements differences among variants
- **Interplanetary Space Logistics**
  - SpaceNet – a NASA-accredited integrated modeling and simulation software environment for modeling space exploration from a logistics perspective
  - Quantifying the impact of modularity, reconfigurability and commonality on space missions; including the impact of temporary scavenging (cannibalization)
  - Mission scenario development and modeling of space tugs
  - Extracting lessons learned from past human spaceflight missions at NASA

# 補助的な分野

- Systems Architecture and Engineering
  - 開発初期における曖昧さを減らすための抽象化、創造性の強化、複雑さの管理
  - 既存のシステムの解析
  - 要求の定式化、目標の定義、機能の分解、形状関数によるマッピングとモジュール化
  - ネットワークやグラフ理論、抽象代数学、目標過程モデリングが主な手法
- Multidisciplinary Design Optimization (MDO)
  - 多数の相互作用を持った複雑なシステムの性能最適化やコスト削減
  - 数学的なコンピュータによる設計法
- Integrated Modeling and Simulation
  - 製造や運用で期待されるシステムや製品の挙動と建築や設計の決定と関連したシステムモデル
  - 忠実性とシミュレーションの効率を向上させながら、多くの専門分野にわたるモデルの構築を支援する

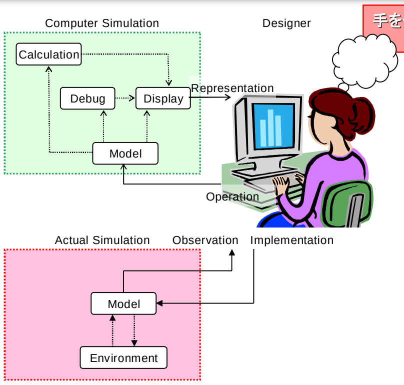
# 特定の方法など

- **Systems Architecture and Engineering**
  - Isoperformance: a methodology for obtaining sets of designs that meet desired performance targets, while minimizing secondary cost and risk objectives
  - SMI – Singular Value Modularity Index, a measure of modularity of systems based on singular value decomposition (SVD) of the underlying system design structure matrix (DSM)
  - Augmented network representations of systems using graph theory with multi-partite node and weighted edge representations
  - A functional classification of complex systems
- **Multidisciplinary Design Optimization (MDO)**
  - Isoperformance – a method for obtaining sets of designs that meet a vector of performance targets within some numerical tolerance, while minimizing secondary objectives
  - Adaptive Weighted Sum (AWS) multiobjective optimization
  - Integrated System Level Optimization for Concurrent Engineering (ISLOCE) – including results from trials with human teams of designers
  - Coupled vehicle design and network flow optimization for complex transportation systems
  - Variable chromosome length genetic algorithm
  - A modular state-vector based modeling and optimization approach. Application to Diesel exhaust after-treatment architectures
- **Integrated Modeling and Simulation**
  - A fast time-domain solver for linear time-invariant (LTI) systems (fastlsim)
  - Integrated modeling and simulation of communications satellites, including satellite constellations
  - A spatial Nyquist-criterion based method for "sizing" the finite element meshes of dynamical structures with application to telescope structures

# 具体例

- **Siddiqi A., de Weck O., Iagnemma K., "Reconfigurability in Planetary Surface Vehicles: Modeling Approaches and Case Study", Journal of the British Interplanetary Society (JBIS), 59, December, 2006.**
- **Siddiqi A., de Weck O., "Spare Parts Requirements for Space Missions with Reconfigurability and Commonality", Journal of Spacecraft and Rockets, 2006, 44 (1) , 147-155, January-February 2007.**
- **de Weck O.L., Simchi-Levi D., "Haughton-Mars Project Expedition 2005", Final Report, NASA/TP-2006-214196, January 2006.**
- **Taylor C., Song M., Klabjan D., de Weck O., and Simchi-Levi D., "Modeling Interplanetary Logistics: A Mathematical Model for Mission Planning", AIAA-2006-5735, 9th International Conference on Space Operations, SpaceOps 2006, Rome, Italy, 19 – 23 June, 2006.**
- **Silver, M., Li X., de Weck O., Shull S., Gralla E., "Autonomous Logistics Technologies for Space Exploration: Experiment Results and Design Considerations", AIAA-2006-5683, 9th International Conference on Space Operations, SpaceOps 2006, Rome, Italy, 19 – 23 June, 2006.**

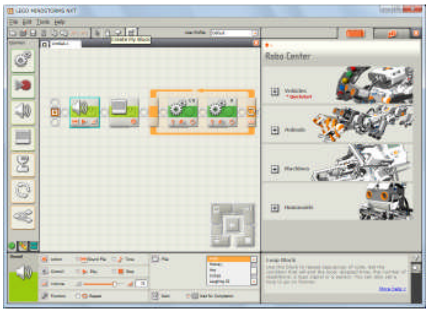
# 事例2 コンピュータと実機によるシミュレーション



手を使って実際作業してみることによる気付き

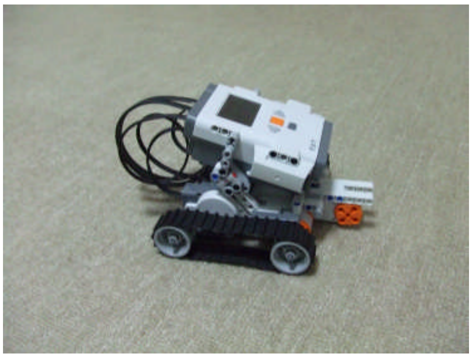
# 事例2 LabVIEWをベースにした開発環境

Mindstormsを利用したLogistics Network運用アルゴリズム開発



- ➢入力（センサー）と出力（モーター）を持つロボットを簡単に製作できる
- ➢制御プログラムによりロボットを動かせる
- ➢簡単に制御プログラムが組める
- ➢複雑なプログラムも組める
- ➢Bluetooth通信を利用して遠隔操作できる
- ➢マスタースレーブ方式のネットワークに対応している

# Mindstorms First Model



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# 今後の検討

- 大学でもできるシミュレーションと実験を組み合わせた研究
- 大学でもできるAnalog siteによるフィールドテスト