Bioastronautics Curriculum Lecture Topic Outline (from 20 June 2017 Workshop Notes)

I. Space Program/ History/ Policy/ Operations

Fundamentals of Bioastronautics / Introduction to Human Spaceflight

Spaceflight History
- Rocketry
- Key historical people and events in spaceflight
- Human programs
- Satellites
- Aerospace medicine
- Mishaps / accidents / anomalies / lessons learned

Space Programs
- Current programs
- Future programs
- Commercial programs
- Organization
- International cooperation
- Long-term colonization
- Rationale

Space Policy
- Setting policy
- Ethics
- Laws, agreements, treaties
- Needs, guidelines and objectives
- Budgets

Space Operations
- Working in space
- Mission control
- Planning
- Ops training
- Payloads / experiments / research
- Automation
- Human interfaces
- Mission design
- Orbital ops
- Surface ops
- EVA
- Application / Utilization / Manufacturing / Mining

Spacecraft
- Architecture

- Life support requirements
- Spacecraft systems
  - Current and future technologies
  - Expendable vs recyclable / regenerable
- Analogs
- Habitability / Crew accommodations
- Habitat design

Physiological / Biological
- Space environment
- Physiological and psychological effects of spaceflight on humans
- Countermeasures
- EVA physiology
- Medical operations / equipment
- Effect on biological (non-human) organisms

Personnel/People
- Career opportunities / paths / planning
- Astronaut selection
- Operations
- Training
- Research
- Human factors

Ethics
- Define space ethics
- Describe ethical differences (cultural, etc)
- Describe unwritten laws among crews
- Medical ethics
- Planetary protection

Laws, agreements, treaties
- Describe applicable space laws
- Identify responsible organizations
- Describe ITAR
- Describe international space agreements
- Describe enforcement options

Application / Utilization / Manufacturing / Mining
- List possible space applications
- Describe advantages and challenges of space manufacturing
- List resources obtainable from space
- Describe challenges of mining in space

II. Space Habitat Design

Human Space Mission Objectives and Requirements
- Space Environments – Orbit, Planets, Moons and other NEO's
- Human Physiological Requirements
- Ergonomics, Human Factors and Psychological Influences on Design

Defining and Sizing Spacecraft Elements
- 'Human in the Loop' / Human-Centered Design
- Determining Habitable Volume
- Defining Atmosphere Conditions

Environmental Control & Life Support Subsystem (ECLSS) Functions
- Atmosphere Management
- Water Management
- Food Supply
- Waste Processing

Crew and Payload Accommodations (CA and PA)

Spacesuits and Extravehicular Activity (EVA)

Subsystem Integration and Interface Definitions
- Orbit Selection / Ascent / Entry / Descent / Landing
- Structures
- Command, Control and Communication (C3)
- Power Management and Thermal Control
- In situ Resource Utilization (ISRU)
- Spacecraft Propulsion and Launch Vehicles

Design Validation and Operations
- Trade Studies and Equivalent Systems Mass (ESM) Analysis
- Human-Rating Process
- Risk Management and Mitigation Strategies
- Cost Estimating
- Requirement Compliance Verification
- Launch and Mission Operations

III. Space Life Sciences

The Space Environment
- Weightlessness, Vacuum, Thermal Extremes, MMOD, Radiation
- Planetary Surfaces

Basic Human Life Support Requirements
- Respiration and the Oxygen Cascade
- Nutrition and Temperature Regulation
- Metabolic Byproducts / Waste Streams

Human Physiological Responses to Orbital Flight
- Basic Responses (hydrostatic and structural) and Motor Control
- Chronobiology and Hormonal Regulation
- Immunological System
- Neuro-Sensory System
- Cardiovascular System
- Visual Impairment
- Musculoskeletal System
- Physiology of Extravehicular Activity (EVA)

Space Life Science Research and Operational Medicine
- Biomedical Countermeasures and Space Medicine
- Radiation Challenges
- Gravity Dependent Physical Processes
- Microgravity Simulation on Earth and Artificial Gravity in Space
- Microbial Responses, Omics and Related Crew Health Issues
- Space Biology and Biotechnology
- Plant and Animal Research in Space
- Psychological-Sociological Aspects
- Astrobiology

Additional Space Life Sciences Discussion / Topics

Exploration Atmosphere:
- N2 , H2O, CO2, O2
- Particles
- VOC
- ECLSS

Integrated Body vs. by Subsystems:
- No One Really Knows How to do this well!!
- Integrate After vs. Before
- w/CM’s
- Or Forms vs. Function (Anatomy vs. Biology)

Unique Aspects of Micro-g on Life
- Fluids/hydrostatic Grad
- Tissue Weight
- Steady Gravity Levels and Subsequent Transition
- Medical vs. Engineering Problems (Should be Both)

Radiation:
- Shielding in non-Earth Context
- Radiation Types
- Real Risk Assessment
- Countermeasure Matching

Microgravity Ocular Syndrome (VIIP)
- CM
- Mechanism/Etiology
- Conflicting Research
- Education Based on Unique Aspect of Microgravity
- First Principles
- Examples

Spacecraft Microbiome
- Crew Microbiome

Behavioral Health
- Rigorous Science
- Not Anecdotal/ Fluffy
- Interaction Between Phycology and other Areas
- Immunology
- Food
- Relate to HAB/ Selection/ Resources

Artificial Gravity:
- Fundamental Parameters
- We just do not know what is effective
- Subsystem Specific

Countermeasures/ Integrated CM's- How to Integrate into a Lectures

Space Medicine/ OPS:
- Personalized
- Tools/ POC Tech
- Telemedicine
- Surgery in Space/ Dental
- Longevity/ Access to Med's

Planetary EVA

- Relevant differences from microgravity and Biomechanics, Heart, Injury, Medicine
- DCS
- Automation and Robotics (maybe in Human Factors or arch.)
- Respiration of Dust

Microbiome

- Microgravity Changes
- Confinement Changes
- Omics Based Research
- Radiation Effects
- Virology/ Pathogens

Astrobiology/ Plants/ Animals

- Life Continuum
- We Tend to Focus on Humans
- Psychology
- ECLSS
- Nutrition
- Multigene Rational Effects

Human Performance (maybe not SLS but Related)

- Communication
  - Technical
  - Inter personal
- Automation/ Robotics Trade Off

IV. Microgravity Sciences

The Acceleration Environment

- Identify & differentiate between gravity environments (hypo-g to 1g to hyper-g)
- Weight or Motion
- The Equivalence Principle
  - Identify & differentiate between gravity environments
  - Demonstrate the equivalence principle
  - List/enumerate effects and disturbances on ISS (including gravity gradient and aerodynamic torque)
  - Describe magnitude or relative importance

Fundamental Physics of Microgravity

- Gravity-dependent vs. –independent Forces
- Effects of Gravity on Physical Phenomena
- Governing Equations
- Non-dimensional Relationships, Scaling Laws and Relative Magnitudes
  - Define system forces & magnitude / importance

- Describe first principles
- Write governing equations
- Relate non-dimensional numbers to an application
- Apply scaling to predict prototype performance through an engineering device
- Develop mathematical models to analyze and simulate gravity dependent processes

Fluids

Natural Convection and Heat Transport
Modeling Continuum (bulk) to Discrete (particle) Transition
Multiphase flows
Granular Flows, Foams and Plasma
Wall Effects and Related Forces (interfacial forces/fluid-structure interactions)

- Explain the transport mechanisms and effects of ug on each
- Describe & differentiate fluids (e.g. gas, Newtonian/non-Newtonian liquids, foams, plasma, multiphase fluids, etc.)
- Describe interfacial forces/fluid-structure interactions
- Describe relative importance of interfacial forces in different gravity environments
- Describe influence of ug on fluid stability; calculate stability criteria

Life sciences

Human physiology and mathematical modeling
Gravity-dependent Responses of Microbes, Plants and Ecosystems

- List biological processes affected by ug environment
- Propose means to mitigate adverse effects
- Describe biological adaptation to the ug/reduced gravity environments

Materials, Structures and Manufacturing

Solidification, Crystallization, Colloids, etc.
Structural Load Propagation

- Describe gravity-dependent materials phenomena (effects on solidification, flocculation, etc.)
- Apply ug environment to synthesize materials & manufacture space structures
- Describe how to utilize ug environment to create unique materials/structures
- Describe how "weak" forces can impact synthesis and manufacturing

Combustion

Flame Propagation and Soot Formation
Cool Flames
Fire Detection and Suppression
Fun – science fiction space movie special effects vs "real world" physics

- Describe factors affecting flammability
- Name differences in combustion processes (diffusion flames, propellants, ..) & products between ug and 1g
- List technologies to detect fire in ug

Associated Research Hardware and Facilities

- Ground Hyper-g Platforms (centrifuges, sleds)
- Simulation of Reduced Gravity (clinostats, drop towers, parabolic flight, etc.)
- Fluid Handling in a Spacecraft
- Flight Simulation of Fractional to Hyper-gravity
- Biological Payloads
- Materials and Combustion Payloads
    - Describe the means to simulate the different acceleration environments
    - Explain differences between each simulation method
    - Describe science payloads and their purpose

Laboratory experimental techniques (or Experimental Methods)

- Methods & limitations
- Testing & integration
- Instrumentation/sensors and Data Acquisition
- Computational analysis (software)
    - Design experiments with consideration for effects of the acceleration or gravity environment

Application/lab component

- Experimental investigation
- Case studies – buoyancy, capillarity, etc.
    - Explain observations of physical phenomena
    - Apply course material via a hands-on experiment

Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies, Committee on Microgravity Research, Space Studies Board, National Research Council, ISBN: 0-309-51867-9, 224 pages, 8.5 x 11, (2000), http://www.nap.edu/catalog/9452.html

Microgravity Science and Technology, Springer, http://www.springer.com/engineering/mechanical+engineering/journal/12217

Microgravity: A Teacher's Guide with Activities in Science, Mathematics, and Technology, https://www.nasa.gov/pdf/62474main_Microgravity_Teachers_Guide.pdf (Note: K-12 focused)

V. Other Potential Courses (*covering select topics in depth*)

History of Spaceflight

Space Policy

Manufacturing in Space

Asteroid Mining

Space Systems Engineering

- could use human space habitats as an example throughout, but focuses on the methodologies and systematic approach

Spacecraft Life Support Systems

Spacecraft & Habitat Environmental Control & Life Support Systems (ECLSS)
Life Support Systems for Extravehicular Activity (EVA)
Atmosphere Revitalization and Control Systems
Thermal Control Systems
Water Recovery & Treatment
Waste Management
Food
Environment & Mission
Modeling & Analysis
Operational considerations
Sensors
Measurement Uncertainty
Technology Readiness Levels (TRL)
Equivalent System Mass (ESM)
Experimental Investigations

Closed-loop regenerative life support systems

Should this be more of central aspect? or integrated with each loop (i.e., atmosphere, thermal, water, waste, food, etc.)

Might require a basis of understanding of each of the systems and then an added focus on closing the loops and reducing the required resupply

Space Radiation Effects and Protection Strategies

Gravitational Biology

Artificial Gravity

Planetary Resources / In situ Resource Utilization (ISRU)

Resource Survey and Definition: what are the in-situ resources existing beyond Earth?

Prospecting: how to detect and characterize the state of resources on the Moon, Mars and beyond
Acquisition: how to mine, extract or collect the raw materials containing desired resources
Refinement: how to convert a raw material into a purified feed stock for utilization
Storage: how to store resources for future utilization
Utilization: what various resources can be used for and how to deliver them for use
Incorporation of ISRU into a Mission Design: how does ISRU affect the critical components of a mission including power, mass, volume, human operations, robotic operations and mission safety and reliability?

what is out there that can be taken advantage of (prospecting, collection, refinement, storage, and utilization - based off of mining operations)
water and oxygen, regolith (maybe less so on the gold and platinum, etc.)
how does this affect the mission design, operations, astronaut tasks, etc.
this should incorporate which of these processes depend upon gravity/microgravity
some of this can be quite open-ended as these are often open research questions, but the mindset is thinking about complications is critical
how does this integrate with current vehicle designs (e.g., current rockets require almost perfectly refined fluids, does this require different vehicle or rocket designs?)
what the long-term, robustness issues?
how does the remoteness impact the requirements and/or design? what are the failure modes?
how does that impact our risk posture?

Human Space Physiology

Classical Space Physiology (bone, muscle, cardio, neurovestibular, renal)
Human Space Exploration show-stoppers
Radiation, psychology, ocular, unanticipated interactions (psychological and physiological)

Non-human life forms

Payload Design

- had been previously taught by Alex Hoehn (CU), but not recently
- this should include integration with the vehicle system and also cover operations
- maybe this should include a hands on lab
- should this be life sciences payload specific? Or payload in general? Or do we mean payloads that study or are operated by humans

Omics and molecular biology in space life sciences

Current research topics seminar similar to a journal club

Statistics and experimental design – maybe not SLS, but very important

Analog environments (maybe not a full course)
Expedition environment

Space Operations Perspective - influence on mission and vehicle design
Integration with ground operations (particularly for future deep space exploration where there may be time delays)
Allocation functions and responsibilities during a mission (could fit with human performance)

Countermeasures and nutrition
These might impact with the design of the space habitat
Particularly important for psychology, behavioral and human health, longer duration missions
Design it as the astronaut's "home" for an extended period of time
Should also be introduced at the time you discuss the problem in an overview style course
Relates to the interaction problem
Great area for hands-on aspects of design
- again this could be integrated into something like space habitat design AND/OR something like space life sciences, BUT it could also be separate
- to fill this out, we might want to consider both physiological countermeasures, but also psychological, psychosocial, and cognitive countermeasures
- artificial gravity could and probably should be integrated here
- this really bridges the phsysiological needs, but also the engineering requirements (vibrations, loads, MPV, etc.)

Low-resource engineering (Space McGyver class)
Your countermeasures break, i.e. exercise bike, so what do you do?
Fundamentally derived from the understanding of physiology and adaptation
Very hands on as well

Space Medicine

Medical issues for deep space exploration
For going beyond LEO and having the option for evacuation
Designing for off-nominals and emergencies, this is likely to be become a major part of future systems

Space architecture
Sequencing/staging, multi-asset missions, mission optimization, rendezvous/docking, compatibility
Human and robotic integration, teaming, function/task allocation, scheduling

Course on mathematical modeling of human, human-habitat systems
- this could be integrated into existing courses, but the takeaway is we can take steps towards being more quantitative and less just descriptive

- what validated models exist that are open source?
- this would include basic physiological models (in response to space/microgravity), but also interactions with the vehicle/habitat system
- these models can and probably should include probabilistic approaches (e.g. probabilistic risk assessment, Monte Carlo simulations)

Spacesuits and Extravehicular Activity

Could be taught in parallel to space habitat design or completely separately, although there obviously are unique aspects (mostly mobility and dexterity, unique technologies)

- new designs for spacesuit cooling on Mars
- materials selection and optimization
- integration with the external design of the spacecraft (hand rails on the external) and navigation issues
- physiological performance of the occupant of the spacesuit and feeding that information back to the occupant (displays of information)
- display information of procedures and associated engineering challenges
- planetary/surface vs. microgravity spacesuits (issues of falling down, CG and total mass management, dust issues--materials, seals, health aspects, where dust deposits, impact on seals and materials, differing ground traction, etc.)
- gas pressurized vs. advanced space suit concepts
- spacesuit assessment, measurement, and performance
- micrometeroid and orbital debris protection, depressurization operational approaches
- closely tied in with the concept of operations - what does the occupant need to do, how can you design the environment/task to allow for the constrained capabilities of a suited human
- tool/interface/manipulator design
- anthropometrics of humans, handbook, particularly accounting for individual differences in capabilities
- how do you augment the human's capabilities using suit design (augmented visual scene, sensor capability, also actuator capability using neuromuscular control with EEG). also need the "third hand" to hold onto things to maintain position but then do activities
- training vs. space operations (analog design and approach)