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# Space Operations – Value-Added Programs for Students on a Limited Time-Budget

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## Abstract

The rapid expansion of civil, commercial, and defense space activities has increased demand for engineers with spacecraft systems and mission operations expertise. While traditional aerospace curricula emphasize aerodynamics, structures, and orbital mechanics, structured undergraduate exposure to spacecraft integration, communications architecture, and operational mission design is often limited. Simultaneously, students and working professionals face constrained credit capacity, making extended degree programs impractical.

This paper describes the development of a 15-credit Space Operations minor designed to deliver operationally focused aerospace preparation within existing undergraduate degree pathways. The program integrates two upper-division core courses—mission and spacecraft design and aerospace communications—with strategically selected electives to provide systems-level integration and subsystem depth. Emphasis is placed on mission trade studies, link budget analysis, subsystem coupling, and applied design projects reflecting real operational constraints.

The resulting model demonstrates how focused curricular integration, rather than expansion, can strengthen spacecraft operations education while preserving time-to-degree efficiency. By leveraging existing institutional capabilities and aligning instruction with active research and regional space activities, the program offers a scalable framework for enhancing workforce readiness in the evolving aerospace sector.

## I. Introduction

Space operations have become a central element of modern aerospace activity. Satellite constellations now support communications, navigation, Earth observation, scientific research, and national security missions at unprecedented scale. Launch cadence continues to increase, and operational complexity has expanded with the proliferation of small satellites and distributed architectures.

This growth has created strong demand for engineers and technologists with spacecraft systems and mission operations expertise. However, many graduates of traditional aerospace programs encounter spacecraft integration, communications, and operations concepts for the first time in industry. At the same time, students and working professionals often face limited time availability, making additional degrees or extended coursework impractical.

## II. Workforce Demand and Educational Gap

Industry and government analyses indicate sustained demand for personnel with space operations expertise. According to the US Bureau of Labor Statistics, aerospace engineering and operations-related occupations are projected to grow faster than the average for all professions over the next decade.

Commercial and government launch activity has increased substantially over the past decade. The global space economy exceeded $500 billion in 2023, with significant growth driven by satellite services and launch activity, further reinforcing workforce demand across spacecraft development and operations sectors. According to FAA Office of Commercial Space Transportation reports, licensed US commercial launches have grown from fewer than 30 annually in the mid-2010s to over 100 launches per year in recent reporting cycles. Global orbital launch attempts similarly exceeded 200 in 2023, reflecting sustained growth in both government and commercial missions.

In parallel, the number of active satellites in orbit has increased dramatically due to large constellations and small satellite deployments, increasing operational complexity and lifecycle management demands. Large commercial constellations such as SpaceX's Starlink system, which has deployed thousands of satellites to low Earth orbit, and OneWeb's broadband constellation have significantly increased the number of operational spacecraft requiring continuous command, control, collision avoidance, and lifecycle management.

Government initiatives, including NASA's Artemis program and proliferated low Earth orbit architectures supporting national security missions, further contribute to expanded operational demands. These distributed and high-tempo mission architectures require engineers proficient in telemetry, tracking, command systems, systems integration, and mission assurance across large fleets of spacecraft rather than single-mission platforms.

The expansion in launch cadence and satellite deployments has corresponded with increased demand for launch range personnel, mission integration engineers, satellite communications specialists, and spacecraft operations teams. FAA and industry workforce analyses note that commercial launch providers, constellation operators, and supporting range organizations face sustained demand for technically trained personnel capable of integrating spacecraft systems, managing telemetry and command architectures, and supporting mission assurance across the full lifecycle. As satellite constellations expand and launch frequency increases, the need for engineers prepared in operational spacecraft systems continues to grow.

Despite this demand, undergraduate aerospace curricula often emphasize aeronautics or astrodynamics while providing limited exposure to spacecraft systems integration and mission operations. This mismatch motivates the need for targeted, operations-focused educational pathways.

A brief review of peer ABET-accredited aerospace curricula indicates that required undergraduate coursework commonly includes aerodynamics, structures, and orbital mechanics, while dedicated spacecraft systems integration and mission operations content is often elective or reserved for graduate study. This structural emphasis can leave graduates underexposed to operational spacecraft systems thinking prior to entering industry, reinforcing the need for focused integration at the undergraduate level.

## III. Design Constraints

The Space Operations program was developed with several explicit constraints: minimizing additional credit burden, maintaining academic rigor, supporting interdisciplinary participation, and aligning with workforce needs. Rather than creating a new degree, the program integrates a small number of high-impact courses into existing degree structures.

## IV. Program Overview

UAF introduced a Minor in Space Operations beginning in Fall 2025. The program is intended for aerospace engineering students, students in related technical disciplines, and working professionals seeking operational credentials. It builds on institutional strengths in aerospace engineering, atmospheric science, and space research.

| Course | Title | Credits |
|---|---|---|
| AERO/EE F465 | Space Mission and Spacecraft Design | 3 |
| EE F464 | Advanced Communications Systems | 4 |

Table 1a. Space Operations Program Core Requirements

In addition, students must complete at least 8 credits from the approved elective list below.

| Course | Title | Credits |
|---|---|---|
| ATM F433 | Atmospheric Remote Sensing | 3 |
| CHEM F406 | Atmospheric Chemistry | 3 |
| CS F463 | Cryptography and Data Security | 3 |
| CS F465 | Computer and Network Security | 3 |
| EE F461 | Communication Systems and Networks | 3 |
| GEOS F422 | Geoscience Applications of Remote Sensing | 3 |
| GEOS F459 | Visible and Infrared Remote Sensing | 3 |
| ME/AERO F452 | Introduction to Astrodynamics | 3 |
| PHYS F462 | Geometrical and Physical Optics | 3 |

Table 1b. Space Operations Program Elective Requirements

## V. Core Courses

### *AERO 464 – Aerospace (Satellite) Communications Systems*

AERO 464 is an upper-division technical elective cross-listed with electrical engineering. The course introduces satellite communications systems with emphasis on space-to-ground links, telemetry, tracking, command, and operational performance.

Learning objectives include link budget analysis, communications architecture design, evaluation of antenna and modulation choices, and integration with ground systems.
Major modules include communications fundamentals, link analysis, TT&C systems, antennas and propagation, modulation and data handling, and ground station integration.

| Module | Topics Covered | Operational Emphasis |
|---|---|---|
| Communications Fundamentals | Signals, noise, RF basics | Space-qualified constraints |
| Link Budget Analysis | Gains, losses, margins | Mission reliability |
| TT&C Systems | Telemetry, tracking, command | Spacecraft control |
| Antennas & Propagation | Patterns, polarization | Coverage and access |
| Modulation & Data | Throughput, encoding | Ops-driven tradeoffs |
| Ground Systems | Stations, networks | End-to-end integration |

Table 2a: AERO 464 Major Instructional Modules

*AERO 465 – Mission and Spacecraft Design*
AERO 465 is an upper-division technical elective focused on end-to-end mission and spacecraft design using a systems engineering framework. Students translate mission objectives into spacecraft architectures through requirements definition, trade studies, and subsystem integration.

Learning objectives emphasize mission definition, orbit selection, payload integration, subsystem interaction analysis, and professional communication of spacecraft designs.
Major modules include mission definition, orbit selection, payload integration, subsystem interactions, systems trades, and conceptual spacecraft design projects.

| Module | Topics Covered | Operational Emphasis |
|---|---|---|
| Mission Definition | Objectives, CONOPS | Stakeholder-driven design |
| Orbit Selection | Coverage, access | Mission feasibility |
| Payload Integration | Interfaces, constraints | Mission performance |
| Subsystem Interactions | Power, comms, ACS | Coupled effects |
| Systems Trades | Mass, power, risk | Decision-making |
| Conceptual Design | Vehicle synthesis | Integration readiness |

Table 2b: AERO 465 Major Instructional Modules

Together, AERO 464 and AERO 465 form the academic core of the Space Operations program, providing both systems-level integration and subsystem depth while remaining compatible with limited student time budgets.

VI. Electives and Customization

Elective courses allow students to tailor the minor toward remote sensing, atmospheric science, systems engineering, or autonomous systems, leveraging existing courses to preserve credit efficiency.

| Pathway | Representative Courses | Space Operations Emphasis |
|---|---|---|
| Remote Sensing & Payloads | ATM F433, GEOS F422, GEOS F459, PHYS F462 | Payload operations, data products, mission planning |
| Communications & Cyber | EE F461, CS F463, CS F465 | TT&C, network resilience, space mission security |
| Space Environment | ATM F433, CHEM F406 | Ionospheric and atmospheric effects on missions |
| Mission Architecture | ME/AERO F452 | Orbit selection, mission feasibility, systems integration |

Table 3: Elective Pathways and Space Operations Emphasis

VII. Assessment & Evaluation

Assessment within the Space Operations program is designed to measure both technical competency and applied systems-level understanding, with emphasis on skills relevant to spacecraft and mission operations. Given the applied nature of the curriculum, assessment methods prioritize project-based deliverables, design reviews, and technical communication over traditional examination-only formats.

In AERO 465, *Mission and Spacecraft Design*[1], assessment centers on a team-based conceptual spacecraft design project. Student teams are evaluated on their ability to translate mission objectives into technical requirements, perform mission trade studies, integrate spacecraft subsystems, and communicate design decisions through written reports and oral briefings. Rubrics emphasize systems thinking, traceability between requirements and design choices, and consideration of operational constraints.

[1]*AERO 465 was introduced as part of the formal Space Operations minor beginning Spring 2026. Prior related content was delivered within existing aerospace coursework but not as a dedicated mission and spacecraft design course.*

In AERO 464, *Aerospace Communications Systems*, assessment focuses on analytical problem sets, subsystem design exercises, and a communications system design assignment. Students are evaluated on their ability to construct and analyze link budgets, assess the impact of environmental and operational factors on communications performance, and integrate spacecraft and ground segment considerations.

Across both courses, technical communication is explicitly assessed through written documentation and oral presentations consistent with aerospace industry practice. Where feasible, assessment artifacts are aligned with real mission scenarios and ongoing research activities to reinforce authenticity.

As the Space Operations program matures, planned assessment includes longitudinal tracking of student outcomes, including placement in space-related internships, senior design projects, graduate research, and early-career positions. These data will be used to refine course content and ensure continued alignment with workforce needs.

*Initial Enrollment and Participation*

Since Fall 2023, AERO 464 (Aerospace Communications Systems) has enrolled 6 students in its initial offering, 2 students in Fall 2024, and 7 students in Fall 2025. Enrollment has included undergraduate aerospace engineering students as well as graduate students seeking advanced preparation in spacecraft communications and mission systems integration.

AERO 465 (Mission and Spacecraft Design), first offered in Spring 2026 under the Space Operations framework, enrolled 8 students in its inaugural semester. Participants included undergraduate students in electrical and mechanical engineering, master's-level students, and two doctoral students from Space Physics. Notably, two enrolled students are actively involved in sounding rocket programs at UAF and the Poker Flat Research Range (PFRR), reinforcing the program's direct connection to ongoing mission activities.

Enrollment in AERO 465 occurred without formal advertising beyond standard course listings, suggesting pre-existing student demand for structured spacecraft systems and mission integration coursework. Together, these data establish a baseline for longitudinal tracking of participation and workforce alignment as the minor matures. Enrollment diversity across undergraduate, graduate, and operationally engaged students suggests broad applicability of operations-focused systems instruction.

## VIII. Operational Impact & Regional Integration

The program leverages regional research and operational assets, including atmospheric research facilities, sounding rocket ranges, and spaceport operations, to provide hands-on experiences, internships, and applied research opportunities.

*Application of Space Operations Knowledge to Current Alaska-Based Operations*

The Space Operations program provides value both to traditional undergraduate students and to personnel currently engaged in Alaska-based space operations. The curriculum emphasizes practical systems knowledge, operational constraints, and mission-level integration directly applicable to ongoing regional activities.

At the University of Alaska Fairbanks Alaska Satellite Facility (ASF), space operations coursework supports personnel involved in satellite mission planning, data acquisition, and ground segment operations. Knowledge gained in mission design, orbital mechanics, and satellite communications directly applies to scheduling satellite passes, understanding coverage and latency tradeoffs, assessing link margins, and interpreting how spacecraft design decisions affect data products and operational reliability.

Within UAF's Space Systems Engineering Program, including nanosatellite development and associated ground station operations, the Space Operations curriculum provides a formal academic foundation for student and staff participation in spacecraft integration and operations. Courses in mission and spacecraft design strengthen understanding of subsystem interactions and operational tradeoffs, while communications coursework supports command and telemetry operations, ground station configuration, and troubleshooting during on-orbit operations.

The program also aligns closely with the operational needs of the Alaska Aerospace Corporation and its activities at the Pacific Spaceport Complex on Kodiak Island. Knowledge of launch vehicle environments, mission timelines, communications requirements, and systems integration prepares students and professionals to support launch operations, range safety coordination, and mission assurance activities. The emphasis on end-to-end mission lifecycle reinforces the connection between spacecraft design decisions and launch and operational constraints encountered at the spaceport.

## IX. Ecosystem Development and Workforce Resilience

The Space Operations minor contributes to long-term workforce resilience by intentionally linking undergraduate instruction, applied research, operational facilities, and industry engagement within a coherent regional aerospace ecosystem. Rather than functioning solely as an academic credential, the program is structured to strengthen feedback loops between education, research, and operational practice.

Figure 1 illustrates the Alaska aerospace ecosystem in which the program operates. At the center lies undergraduate instruction in mission and spacecraft design and aerospace communications. These courses provide systems-level preparation that directly supports applied research activities, including nanosatellite development, atmospheric research missions, and ground segment operations. In turn, research programs inform course content by introducing real-world constraints, operational anomalies, and contemporary mission architectures into the classroom.

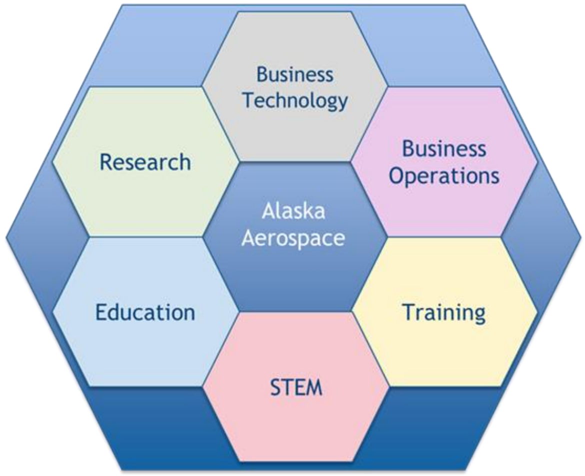

Figure 1: Alaska Aerospace Ecosystem

This bidirectional relationship strengthens workforce resilience in several ways. First, it reduces the lag between emerging operational practices and academic preparation. Second, it exposes students to mission-relevant problem-solving prior to entering industry. Third, it supports mid-career professionals by providing formalized systems training aligned with current operational responsibilities.

The ecosystem perspective also enhances regional economic stability. By preparing students for roles in spacecraft operations, mission integration, and launch support, the program contributes to sustaining Alaska-based aerospace activities. Workforce continuity is particularly important in geographically remote regions where recruiting experienced personnel can be challenging. Developing local technical capacity through focused educational pathways increases institutional memory, operational reliability, and long-term viability of regional aerospace initiatives.

Finally, the minor supports scalability. As launch cadence and satellite activity increase nationally, educational programs that integrate seamlessly into existing degree structures offer a sustainable pathway for expanding workforce preparation without requiring wholesale curriculum redesign. In this way, the Space Operations minor serves both regional and national workforce resilience objectives.

*Future Program Expansion and Workforce Development Opportunities*

The Space Operations minor provides a foundation that can be expanded to further strengthen operations-focused education within UAF's aerospace and technical programs. One natural extension is the formal integration of Space Operations coursework as an operations emphasis or track within the aerospace engineering degree. This approach will allow students to graduate with a traditional aerospace engineering credential augmented by explicit preparation for spacecraft operations, mission planning, and systems integration roles.

Such an expansion could include recommended course sequences, capstone projects with operational partners, and coordinated use of Alaska-based facilities for experiential learning. Embedding space operations content within the aerospace engineering curriculum would help bridge the gap between analysis-focused coursework and the practical demands faced by graduates entering spacecraft development and operations organizations.

A second opportunity lies in extending space operations workforce development through the University of Alaska Fairbanks Community and Technical College (CTC) aviation and technical programs. By adapting selected Space Operations course modules, laboratories, or short-format credentials, UAF could support technicians, operators, and mid-career professionals involved in launch operations, ground systems, communications, and mission support roles.

This layered approach—spanning technician-level training through undergraduate engineering education—strengthens Alaska's space workforce pipeline while preserving the limited time-budget philosophy central to the Space Operations program. Together, these efforts enhance regional workforce resilience and support sustained growth of Alaska's aerospace ecosystem.

## X. Transferability and Recommendations

Although the Space Operations minor leverages several Alaska-specific operational assets, its core structure is broadly transferable to other institutions. The defining feature of the model is not geographic advantage, but the deliberate integration of focused operational coursework within existing degree pathways.

Several characteristics enhance transferability:

*1. Credit Efficiency*. The program requires only two upper-division core courses supplemented by existing electives. Institutions with aerospace, electrical engineering, atmospheric science, or related programs can replicate this structure without extending time-to-degree or adding excessive credit burden.

*2. Leveraging Existing Infrastructure.* Rather than requiring new laboratory facilities or faculty lines, the model builds on courses and research capabilities already present in many engineering colleges. Communications, systems engineering, and astrodynamics courses often exist independently; the innovation lies in framing and integrating them under an operational mission-oriented emphasis.

*3. Modular Expansion Capability.* Institutions may scale the model incrementally — beginning with a course pair or certificate, then expanding to a minor or formal track as enrollment and industry demand justify growth.

*4. Alignment with Workforce Needs*. The curriculum emphasizes spacecraft systems integration, mission trade studies, communications architecture, and operational constraints—competencies broadly applicable across civil, commercial, and defense space sectors.

For institutions considering adoption of a similar model, several recommendations emerge:

- Conduct a brief curriculum audit to identify gaps in operational spacecraft systems coverage.
- Identify one systems-level design course and one communications or subsystem course that can serve as anchors.
- Align assessment artifacts with real mission scenarios or regional operational activities.
- Establish advisory input from industry or research partners to maintain relevance.
- Implement staged evaluation metrics, including enrollment tracking, internship placement, and early-career outcomes.

By prioritizing integration over expansion, institutions can strengthen operational space education while preserving curricular efficiency. The Space Operations minor provides one such model, illustrating how operationally grounded curricular integration can strengthen workforce preparedness without expanding degree requirements.

## XI. Conclusions

The Space Operations minor demonstrates that targeted curricular design can deliver operationally relevant aerospace education within a constrained academic framework. By integrating mission and spacecraft design with aerospace communications and strategically selected electives, the program provides systems-level preparation aligned with contemporary space workforce needs while preserving limited student time budgets.

The model addresses a structural gap frequently observed in undergraduate aerospace curricula: limited required exposure to spacecraft systems integration and mission operations. Rather than expanding degree requirements or creating standalone programs, the minor embeds focused operational content within existing degree pathways. This approach preserves academic efficiency while strengthening workforce alignment.

Through integration with regional research facilities, launch operations, and applied missions, the program reinforces a broader aerospace ecosystem. Students gain exposure to authentic operational contexts, and mid-career professionals can formalize systems knowledge relevant to ongoing mission activities. This bidirectional relationship between instruction and operations enhances workforce resilience at both regional and national levels.

Importantly, the program's structure is transferable. Institutions with existing aerospace, engineering, or atmospheric science programs can adopt similar operational course pairings without significant new resource commitments. By emphasizing systems integration, communications architecture, and mission-level thinking, such programs can strengthen operational preparedness while maintaining curricular flexibility.

As space activity continues to expand in scale and complexity, educational models that prioritize integration over expansion will be essential. The Space Operations minor provides one such model—demonstrating that meaningful workforce impact can be achieved through focused, credit-efficient, and operationally grounded curricular innovation.

**Appendix A**
**AERO F464 – Aerospace Communication Systems (Integrated Syllabus Summary)**
*Course Level and Credits:* Upper-division undergraduate technical elective, 4 credits.

*Course Description:* AERO F464 covers aerospace and satellite communication systems supporting space missions. Emphasis is placed on space-to-ground link design, telemetry, tracking, and command (TT&C), constellation geometry, orbital dynamics impacts on communications, antenna systems, modulation schemes, and ground station integration. The course explicitly connects spacecraft motion and mission geometry to communications system performance.

*Learning Outcomes:* Upon completion of the course, students are able to design communication systems meeting mission requirements; perform detailed link budget analyses; evaluate antenna, power, and modulation tradeoffs; relate orbital dynamics to communications constraints; and apply modern engineering tools to spacecraft communication system design.

*Major Course Elements:* Instruction combines lectures, weekly problem sets, laboratories, and a team-based topic paper and briefing focused on real-world communication systems. Laboratory activities include orbital visualization, ground track and coverage analysis, and GEO/MEO/LEO link design. Facility tours and applied demonstrations reinforce operational context.

*Major Topics (Weekly Outline):*
- Orbital dynamics fundamentals
- Orbit prediction for ground station acquisition & communications
- Communications fundamentals and RF concepts
- Noise, interference, and link margins
- Link budget formulation and analysis
- Antennas and propagation effects
- Modulation, coding, and data rates
- Ground station architecture and networks

*Assessment and Grading:* Student performance is evaluated using a balanced assessment structure: homework (20%), quizzes (10%), two midterm exams (20%), final exam (20%), laboratories (20%), topic paper and briefing (5%), and class participation (5%). Emphasis is placed on analytical proficiency, subsystem design, and professional technical communication.

**Appendix B**
**AERO F465 – Mission and Spacecraft Design (Integrated Syllabus Summary)**
*Course Level and Credits:* Upper-division undergraduate technical elective, 3 credits.

*Course Description:* AERO F465 introduces students to end-to-end space mission planning and spacecraft design. The course addresses the space environment, common orbital regimes, and the design and integration of spacecraft subsystems including structures, attitude determination and control, command and data handling, communications, electrical power, thermal control, propulsion, and payloads. Emphasis is placed on system-level tradeoffs and mission-driven design decisions.

*Learning Outcomes:* Upon successful completion of the course, students are able to explain the effects of the space environment on spacecraft subsystems; identify and describe the function and design principles of major spacecraft subsystems; apply systems engineering methods to develop notional spacecraft designs; and integrate subsystem-level considerations to satisfy overall mission and vehicle performance requirements.

*Major Course Elements:* Instruction consists of lectures, guided discussions, and a semester-long mission and spacecraft analysis project completed by small student teams. The project includes interim design reviews and a final cumulative briefing and report. Course content is organized into space environment modules, spacecraft subsystem modules, and system design modules, reinforcing progressive integration from physics and environment through vehicle-level synthesis.

*Major Topics (Weekly Outline):*
- Mission objectives, stakeholders, and CONOPS
- Orbit selection and mission analysis
- Payload integration concepts
- Spacecraft subsystems overview (power, communications, attitude control, thermal)
- Subsystem interactions and coupling effects
- Conceptual spacecraft design synthesis

*Assessment and Grading:* Student performance is evaluated using homework (10%), quizzes (5%), two midterm exams (20%), a final exam (20%), mission and spacecraft design reviews and reports (40%), and class participation (5%). Assessment emphasizes systems thinking, engineering judgment, technical communication, and the ability to integrate subsystem designs into a coherent spacecraft architecture.

**Appendix C**
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