TDSI

Temasek Defence Systems Institute

MASTER OF DEFENCE TECHNOLOGY AND SYSTEMS PROGRAMME

Information Booklet

2022

Intake

NUS

National University of Singapore

NPS

PRAESTANTIA PER SCIENTIAM

1909

NAVAL POSTGRADUATE SCHOOL

DARE TO

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DELIVER

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About Temasek Defence Systems Institute

Vision

A premier educational institute for nurturing systems thinkers and thought-leadership in systems thinking in defence and security

Mission

To nurture systems thinkers and leaders to advance Singapore's defence capabilities

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Temasek Defence Systems Institute (TDSI) is a strategic alliance between two eminent institutions:

- National University of Singapore (NUS) and
- US Naval Postgraduate School (NPS)

TDSI was established to provide the platform to bring together military staff and defence technologists in an education and research environment. TDSI aims to produce graduates who understand the complexities of a military force, so as to be able to create maximum leverage by the integration of operations and technology.

Breadth + Depth

TDSI's flagship programme is the Master of Defence Technology and Systems Programme.

The masters' programme draws upon the synergies of both NUS and NPS. The aim of the programme is to educate and integrate military staff and defence technologists in planning, designing, developing, creating, operating and sustaining integrated military forces of the 21st century.

Students of this unique Masters Programme will learn by experimenting in a practical environment. They will benefit from the bond building, networking and from the interactions among the military staff, defence engineers and scientists to leverage on the opportunity highly essential for an integrated defence development.

The qualities that the students develop by taking on such an in-depth interdisciplinary experience will better prepare them to confront the challenges of the new millennium.

About Master of Defence Technology and Systems Programme (MDTS)

Objectives

This Programme provides postgraduate education in Defence Technology, Systems Engineering and Integration for military officers, defence engineers and scientists. Graduates from the programme will be:

1. Proficient in the underlying scientific principles of key technologies, both current and future, and their physical boundaries. The emphasis will be on technologies in the key capability areas of Manoeuvre War, Precision Strike, Comprehensive Awareness & Communications and Protection/Survivability.
2. Conversant in applying systems engineering methodologies and processes learnt in analysing the integration and interactions of sub-systems in large-scale systems, so as to optimize the total system performance.
3. Capable of conducting technical studies and lead in operational testing and evaluation (OT&E) efforts to expand systems' operating envelops.
4. Skilled in analysing the impact of future technologies on military operational concepts and how future operational concepts drive technological demands.

Minimum Admission Requirements

1. Bachelor of Engineering (with good honours), Bachelor of Science in Physics or Mathematics (with good honours), or an equivalent qualification acceptable to NUS and NPS;
2. At least 3 years of relevant working experience; and
3. Sponsorship to this Programme by the candidate's employer.

Degrees Awarded

The MDTS is a double-degree programme. The following degrees will be awarded to students who successfully complete all the relevant modules, projects and research thesis at NUS and NPS:

Master of Science (Defence Technology and Systems) degree by NUS	&	**Master of Science degree in a relevant discipline** awarded by NPS

GRE and TOEFL

GRE and TOEFL are not required for admission to NUS for this Programme. However, NPS requires candidates from non-English speaking countries to possess the following TOEFL achievements for admission to programmes in NPS:

1. Score of 83 IBT (Internet Base Test) or 560 (paper based test) for direct entry;
2. Achieve a minimum of 18 in each of the four testing sections of the IBT (reading, listening, speaking and writing);
3. This score is valid for a two-year period; and
4. It must be current at the time of reporting at NPS.
5. For the TOEFL results to be sent directly to NPS, please insert the NPS code "4831" on the TOEFL application form.

Singaporean candidates are exempted from NPS's TOEFL requirement.

Application and Enrolment Schedule

There is one intake each year for this programme. All applications for the March 2022 Intake must reach Temasek Defence Systems Institute by 15 October 2021.

Applicants will expect to be informed on the outcome of their application sometime in January 2022.

Date	Event
15 July 2021	Application Opens
15 October 2021	Application Closes
January to March 2022	Applicants review Engineering Mathematics (E-Module)
10 March 2022	• Registration of Students at NUS • International students apply for Singapore Student Passes
21 March 2022	Start of MDTS Programme in NUS
11 September 2022	Students report to NPS
22 September 2023	End of MDTS Programme in NPS

Academic Dates

The academic programme is based on quarterly cycles. The dates for these quarters are shown in the below table:

Quarter	Dates	Venue
Q1	21 Mar 2022 to 3 Jun 2022	NUS
Q2	6 Jun 2022 to 26 August 2022	NUS
Q3	26 Sep 2022 to 15 Dec 2022	NPS, US
	19 Dec 2022 to 2 Jan 2023	Christmas Break
Q4	3 Jan 2023 to 24 Mar 2023	NPS, US
Q5	27 Mar 2023 to 15 Jun 2023	NPS, US
	19 Jun 2023 to 3 Jul 2023	Summer Break
Q6	5 Jul 2023 to 22 Sep 2023	NPS, US

Structure of Programme

The Programme is structured into two parts:

Common Curriculum	• Common modules conducted at NUS • Integration Project conducted at NPS
Specialised Curriculum	• Specialised modules conducted at NPS • Thesis Research conducted at NPS

The structure of this programme is illustrated in **ANNEX A.**

Curriculum

1. Candidates are required to complete a programme of study comprising the MDTS Common Curriculum and a Specialised Curriculum of the candidate's choice.
2. A brief description of the modules under the Common Curriculum is shown in ANNEX B.
3. The modules under the Specialised Curriculum are existing modules in NPS. ANNEX C describe the modules in each specialisation track.
4. Candidates are expected to take 1.5 years to complete this programme under normal circumstances.

Prerequisites

Candidates are to ensure that they satisfy the relevant prerequisites modules for the selected specialisation track of the MDTS programme.

Examinations

1. Candidates will be examined at the end of each quarter of their study for the coursework modules.
2. The Board of Examiners of the respective universities will decide the examination results of the modules offered at each university. Each university will issue the examination results to candidates reading their respective modules.
3. The universities will exchange results of the students.

Further Information and Contact

1. Students need to provide for their own meals, lodging, transportation, entertainment, books and stationeries. A list of the estimated cost for such expenditure accompanies this booklet.
2. Please visit TDSI's website for more information and updates at https://*tdsi.nus.edu.sg*
3. If you need further clarification, you may contact:
   Ms Wong Hsiao-Szu
   tdswhs@nus.edu.sg

Annexes

Annex A	Master of Defence Technology and Systems (MDTS) Programme Structure
Annex B	MDTS Common Curriculum Course Description
Annex C	MDTS Specialised Curriculum Module Description
Annex D	Guide for International Applicants

Master of Defence Technology and Systems (MDTS) Programme Structure

MDTS Programme Structure

The MDTS programme is divided into two parts, the Common Curriculum and the Specialised Curriculum. Upon completing the course successfully, students will be awarded the following:

- Master of Science (Defence Technology and Systems) degree by NUS; and
- Master of Science degree in a specialised field by NPS.

MDTS Programme Structure				
Quarter		Venue	Common Curriculum MSc (DTS)	Specialised Curriculum MSc (specialisation)
Q1	Mar to Jun	NUS	Coursework	–
Q2	Jun to Sep	NUS	Coursework	–
Q3	Oct to Dec	NPS	Integration Project	Coursework & Thesis Research
Q4	Jan to Mar	NPS	Integration Project	Coursework & Thesis Research
Q5	Apr to Jun	NPS	Integration Project	Coursework & Thesis Research
Q6	Jul to Sep	NPS		Coursework & Thesis Research

The Common Curriculum aims to provide students with a broad range of knowledge pertaining to systems engineering and introduction to key defence technologies. Here, the learning emphasis is on systems thinking. Students have to take all the coursework modules conducted in NUS within the first 2 quarters of the programme. The students then proceed to NPS where they will embark on the "Integration Project" over the subsequent 3 quarters.

The Specialised Curriculum aims to provide students with in-depth knowledge of a specific field in defence technology. Students are required to choose a programme offered in NPS. The Specialised Curriculum (tracks) comprises another 8-10 required coursework modules and a "Thesis Research".

MDTS Programme – Common Curriculum Overview

The common curriculum modules conducted in NUS are shown in the table below.

NUS Degree: Master of Science (Defence Technology and Systems)	
Pre-Course Modules	
	Engineering Mathematics (refresher course)
	Probability and Statistics (refresher course)
Quarters 1 and 2 (Mar to Sep) at NUS Singapore	
DTS5701	Large Scale Systems Engineering
DTS5702	C3 Systems
DTS5703	Operations Research
DTS5731	Fundamentals of Systems Engineering
DTS5732	Artificial Intelligence & Data Analytics
DTS5733	Sensors & Intelligence
DTS5734	Guided Systems
DTS5735	Cyber Security
DTS5736	Systems Design Project
Quarters 3 to 5 (Sep to Jun) at NPS, United States	
	Integration Project conducted at NPS

MDTS Programme – Specialised Curriculum Overview

The specialised field by NPS and the associated degree name are shown in the table below. **The courses in the matrix are provided as a guide only.** Please work with the NPS Academic Associate and Program Officer for actual courses

	Department	NPS Degree	Suggested Matrix
1	Electrical & Computer Engineering	Master of Science in Electrical Engineering (MS EE)* OR Master of Science in Engineering Science (Electrical Engineering) - MSES (EE)*	• Communication Systems • Sensor Systems Engineering - Electronic Warfare or - Radar set
2	Mechanical & Aerospace Engineering	Master of Science in Mechanical Engineering (MS ME)* OR Master of Science in Engineering Science (Mechanical Engineering) – MSES (ME)*	• Weapon Systems Engineering (Missile Systems Engineering Programme) • Autonomous Systems Engineering
3	Computer Science	Master of Science in Computer Science (MS CS)	• Cyber Security and Defense (CSD)
		Master of Science in Modelling, Virtual Environments and Simulation (MS MOVES)	• Modelling, Virtual Environments & Simulation
4	Operations Research	Master of Science in Operations Research (MS OR)	• Operations Research, Modelling & Simulation
5	Physics	Master of Science in Applied Physics (MS AP)	• Free Electron Lasers
		Master of Science in Combat Systems Technology (MS CST)	• Sensor Systems Engineering – General Sensors
6	Oceanography	Master of Science in Physical Oceanography (MS PO)	• Operational Oceanography • Undersea Warfare
7	Applied Mathematics	Master of Science in Applied Mathematics (MS AM) and Certificate in Network Science OR Certificate in Secure Communications	• Applied Mathematics
8	Systems Engineering	Master of Science in Systems Engineering (MS SE)* OR Master of Science in Engineering Systems (MS ES)*	• Systems Engineering
Joint Department and Academic Group Programme			
9	Department of Systems Engineering and Department of Operations Research	Master of Science in Systems Engineering Analysis (MS SEA) degree	• Systems Engineering Analysis (SEA)
10	Space Systems Academic Group	Master of Science in Astronautical Engineering (MS AE)* OR Master of Science in Engineering Science (Astronautical Engineering) – MSES (AE)*	• Space Systems Engineering
		Master of Science in Space Systems Operations (MS SSO)	• Space Systems Operations

Important note on suggested matrices

1. The suggested matrices for the various specialisation fields are shown in the following pages. The courses in the matrix are provided as a **guide**. Please work with the NPS Academic Associate and Program Officer for actual courses. Candidates are to ensure that they satisfy the relevant prerequisites modules for the selected specialisation track of the MDTS Programme. NPS may, on a case-by-case basis, accredit similar modules that students have achieved earlier.

2. For specialisation tracks which are undersubscribed, the exact modules for the track will be determined by the Academic Associate working with the students.

3. The list of suggested specialisation tracks are established with NPS. However, this does not preclude a MDTS candidate from applying to read other master degree programme being offered at NPS, so long as there is agreement between the candidate and the respective sponsor. TDSI will work with NPS to synchronise the duration of master programme with those of the established specialisation tracks.

4. You may refer to the full list of programmes offered by NPS in the NPS course catalogue http://www.nps.edu/Academics/GeneralCatalog/Layout.html

*Accreditation Board for Engineering and Technology (ABET):

1. The MSEE/MSME/MSSE/MSAE degrees from NPS are accredited by the Accreditation Board for Engineering and Technology (ABET). See *www.abet.org* for more details.

2. NPS decides on students' admission to either:
    - MSEE/MSME/MSSE/MSAE degree (with ABET accreditation) or
    - MSES(EE)/MSES(ME)/MSES/MSES(AE) degree (non-ABET accreditation).

1. MDTS Specialised Curriculum

	Department	NPS Degree	Suggested Matrix
1	Electrical & Computer Engineering	Master of Science in Electrical Engineering (MS EE)* OR Master of Science in Engineering Science (Electrical Engineering) - MSES (EE)* **Non-ABET Accredited Degree*	• Communication Systems • Sensor Systems Engineering - Electronic Warfare or Radar set

1.1 Degree Requirement

- A Master of Science in Electrical Engineering or Master of Science in Engineering Science (Electrical Engineering) requires students to complete 36 Graduate-level course work credits of which minimum 12 credit hours must be at EC4000 level. Students must take at least 16 quarter credit hours of thesis.

- Students must complete two specialties contained within one focus area.

- The following table shows the available specialties in each focus area:

Focus Areas ➔ / Specialties 🡇	Communications & Information Engineering	Cyber Engineering	Nano-electronics & Energy Engineering	Sensor & Control Engineering
Choose TWO specialties within one focus area				
Communications Systems	✓	✓		
Network Engineering	✓	✓		
Sensor Systems Engineering	✓			✓
Computer Systems	✓	✓	✓	
Cyber Systems		✓		✓
Guidance, Control & Navigation Systems			✓	✓

1.2 List of Required Courses in Each Specialty

Specialty	Course		Credit Hour
Communications Systems	EC 3500	Analysis of Random Signals	(4-0)
	EC 3510	Communications Engineering	(3-2)
	EC 4550	Digital Communications	(4-0)
	EC 4580	Error Correction Coding	(4-0)
Network Engineering	EC 3710	Computer Communications Methods	(3-2)
	EC 4725	Adv. Telecommunication Systems Eng.	(3-2)
	EC 4745	Mobile Ad Hoc Wireless Networking	(3-2)
	EC 4785	Internet Engineering	(3-2)
Sensor Systems Engineering	EC 3600	Antennas & Propagation	(3-2)
	EC 3630	Radiowave Propagation	(3-2)
	And select either the RADAR or Electronic Warfare set:		
	RADAR		
	EC 4610	Radar Systems	(3-2)
	EC 4630	RCS Prediction & Reduction	(3-2)
	OR		
	Electronic Warfare		
	EC 3700	Joint Network-Enabled Electronic Warfare I	(3-2)
	EC 4680/90	Joint Network-enabled Electronic Warfare II	(3-2)
Computer Systems	EC 3800	Microprocessor Based System Design	(3-2)
	EC 3840	Introduction to Computer Architecture	(3-2)
	EC 4820	Advanced Computer Architecture	(3-2)
	EC 4830	Digital Computer Design	(3-2)
Cyber Systems	EC 3730	Cyber Network & Physical Infrastructures	(3-2)
	EC 3740	Reverse Engineering in Electronic Syst.	(3-2)
	EC 4730	Covert Communications	(3-2)
	EC 4770	Wireless Communications Network Security	(3-2)
Guidance, Control & Navigation Systems	EC 3310	Optimal Estimation: Sensor & Data Association	(3-2)
	EC 3320	Optimal Control Systems	(3-2)
	EC 4330	Navigation, Missile, & Avionics Systems	(3-2)
	EC 4350	Nonlinear Control Systems	(3-2)

1.3 List of Electives

Electives	Course		Credit Hour
Communications Systems	EC 4500	Adv. Topics in Communications	(3-0)
	EC 4510	Cellular Communications	(3-0)
	EC 4530	Soft Radios	(3-2)
	EC 4560	Spread Spectrum Communications	(3-2)
	EC 4570	Signal Detection and Estimation	(4-0)
	EC 4590	Communications Satellite Systems Eng.	(3-0)
Computer Systems	EC 3800	Microprocessor Based System Design	(3-2)
	EC 3820	Computer Systems	(3-2)
	EC 4800	Adv. Topics in Computer Eng.	(3-1)
	EC 4830	Digital Computer Design	(3-2)
	EC 4870	VLSI Systems Design	(3-2)
Electronics Systems	EC 3230	Space Power & Radiation Effects	(3-1)
	EC 3240	Renewable Energy at Military Bases	(3-2)
	EC 3280	Intro to MEMS Design Advanced	(3-3)
	EC 4950	Emerging Nanotechnology	(3-1)
	EC 4280	MEMS Design II	(2-4)
Guidance & Control Systems	EC 4300	Adv. Topics in Modern Control Systems	(3-1)
	EC 4310	Fundamentals of Robotics	(3-2)
	EC 4320	Design of Robust Control Systems	(3-2)
Sensor Systems	EC 3210	Intro to Electro-Optics Systems Eng.	(4-1)
	EC 3610	Microwave Engineering	(3-2)
	EC 4210	Electro-Optics Systems Engineering	(3-0)
	EC 4640	Airborne Radar Systems	(3-2)
Network Engineering	EC 4430	Multimedia Info. & Communications	(3-1)
	EC 4710	High-Speed Networking	(3-2)
Cyber Systems	EC 4715	Cyber System Vulnerabilities & Risk Assessment	(3-2)
	EC 4747	Data Mining in Cyber Applications	(3-2)
	EC 4755	Network Traffic, Activity Detection, & Tracking	(3-2)

1.4 Suggested Matrix

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed courses' availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

- The SE3201/2/3 course sequence is the Integrated Project. All TDSI students must complete this sequence with satisfactory results as part of the MDTS degree requirement.

- Students will have to attend Department seminars, colloquium and introduction to graduate research that are scheduled by the Department.

1	Department	NPS Degree
	Electrical & Computer Engineering	Master of Science in Electrical Engineering (MS EE)* OR Master of Science in Engineering Science (Electrical Engineering) - MSES (EE)* **Non-ABET Accredited Degree*

Focus Areas → / Specialties ↓	Communications & Information Engineering
Choose TWO specialties within one focus area	
Communications Systems	✓
Sensor Systems Engineering	✓

Quarter 3 (Fall)	
EC3500 Analysis of Random Signals ***	
Radar or Electronic Warfare course **	Integrated Project
Elective *	SE3201
EC3000 Introduction to Graduate Research	Eng. Systems Conceptualization
EC0810 Thesis Research	
Quarter 4 (Winter)	
EC3510 Communications Engineering ***	
EC3600 Antennas and Propagation **	Integrated Project
Radar or Electronic Warfare course**	SE3202
Elective *	Eng. Systems Design
EC0810 Thesis Research	
Quarter 5 (Spring)	
EC4550 Digital Communications ***	
EC3630 Radiowave Propagation **	Integrated Project
Elective *	SE3203
EC0810 Thesis Research	Eng. Systems Implementation
Quarter 6 (Summer)	
EC4580 Coding and Information Theory ***	
Elective *	
EC0810 Thesis Research	

***	Required courses for 1st specialty. Refer to list of required courses.
**	Required courses for 2nd specialty. Refer to list of required courses.
*	Electives. Refer to list of electives.

Other Possible Specialty Combinations
• Communication Systems and Sensor Engineering (Electronic Warfare or Radar Focus) • Communication Systems and Network Engineering • Communication Systems and Cyber Systems • Network Engineering and Sensor Engineering (Electronic Warfare or Radar Focus) • Network Engineering and Cyber Systems

Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.

2. MDTS Specialised Curriculum Department of Mechanical & Aerospace Engineering

	Department	NPS Degree	Suggested Matrix
2	**Mechanical & Aerospace Engineering**	Master of Science in Mechanical Engineering (MS ME)* OR Master of Science in Engineering Science (Mechanical Engineering) – MSES (ME)* **Non-ABET Accredited Degree*	• Weapon Systems Engineering (Missile Systems Engineering Programme) • Autonomous Systems Engineering

2.1 Degree Requirement

- A Master of Science in Mechanical Engineering or Master of Science in Engineering Science (Mechanical Engineering) requires students to complete 32 graduate level (3000/4000 level) credit hours. 24 credit hours must be in ME/AE courses of which 12 must be at the 4000 level. 8 credit hours must be from outside the MAE Dept.

- Students must select a Department Discipline and complete 2 courses within that Discipline. The selected Discipline supports the student's **thesis research**. The two courses are part of the 32 graduate hours above.

- Students will have to attend the following modules that are scheduled by the Department:
  - Integrated Project Meetings
  - Department seminars, colloquium and introduction to graduate research

- Special Programs**.** Along with MAE degree programs, the department offers special programs that are sequences of courses along with capstone design projects that focus on the design of important military systems, such as platforms and weapons.
  - Missile Systems Engineering
  - Autonomous Systems Engineering
  - Total Ships Systems Engineering

2.2 Department Discipline Requirement

- In order to complete the requirements for the degree of Master of Science (MSME or MSES(ME)), a specific discipline, supporting the student's **thesis research,** from Mechanical Engineering must be declared.

- The disciplines are listed below in the table below.

Discipline	Complete Minimum TWO Courses Within Each Discipline
Thermal Fluid Sciences	ME4160 Applications of Heat Transfer ME4161 Conduction of Heat Transfer ME4162 Convection of Heat Transfer ME4163 Radiation Heat Transfer ME4202 Compressible Flow ME4211 Applied Hydrodynamics ME4220 Viscous Flow ME4240 Advanced Topics in Fluid Dynamics AE4452 Advanced Missile Propulsion
Shock and Vibrations	ME4522 Finite Element Methods in Structural Dynamics ME4525 Naval Ship Shock Design and Analysis ME4731 Engineering Design Optimization ME4550 Random Vibrations
Solid Mechanics	ME4612 Advanced Mechanics of Solids ME4613 Finite Element Methods ME4620 Theory of Continuous Media
Dynamic Systems and Control	ME4731 Engineering Design Optimization ME4703 Missile Flight and Control (ECE4330) ME4811 Autonomous Systems and Vehicle Control II ME4812 Fluid Power Control ME4821 Marine Navigation ME4823 Dynamics of Autonomous Vehicles ME4825 Marine Propulsion Control
System Design	TS4001 Integration of Naval Engineering Systems TS4003 Ship Design Integration ME4700 Weaponeering ME4704 Missile Design ME4731 Engineering Design Optimization ME4741 Combat Survivability, Reliability and Systems Safety Engineering
Materials Science	MS4215 Phase Transformation MS4312 Characterization of Advanced Materials MS4811 Mechanical Behavior of Engineering Materials ME4613 Finite Element Methods MS4822 Engineering and Science of Composite Materials

2.3 Suggested Matrix for Specialisation Track Weapon Systems Engineering

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

- Students must ensure that a combination of the compulsory and elective courses satisfy the specified 32 credit- hour requirement.

- Students have to check and confirm with the Academic Associate:
  - On the availability of the courses they wish to select.
  - To ensure that their elective combination satisfy the MSME and MSES(ME) degree requirements.

- The SE3201/2/3 course sequence is the Integrated Project. All TDSI students must complete this sequence with satisfactory results as part of the MDTS degree requirement.

- Students will have to attend Department seminars, colloquium and introduction to graduate research that are scheduled by the Department.

	Department	NPS Degree
2	**Mechanical & Aerospace Engineering**	Master of Science in Mechanical Engineering (MS ME)* OR Master of Science in Engineering Science (Mechanical Engineering) – MSES (ME)* **Non-ABET Accredited Degree*
Specialisation Track		Weapon Systems Engineering (Missile Systems Engineering Programme) • Pre-requisite Modules: NIL • Other Specific Skills Needed: Must have BSME or Equivalent for MSME

Quarter 3 (Fall)	
AE4452 Advanced Missile Propulsion ***	Integrated Project
Electives *	SE3201
ME1810 Thesis Proposal Preparation	Eng. Systems Conceptualization
Quarter 4 (Winter)	
ME4703 / (EC4330) Missile Flight and Control ***	Integrated Project
Electives *	SE3202
ME0951 MAE Seminars	Eng. Systems Design
ME0810 Thesis Research	
Quarter 5 (Spring)	
ME3205 Missile Aerodynamics ***	Integrated Project
Electives *	SE3203
ME0951 MAE Seminars	Eng. Systems Implementation
ME0810 Thesis Research	
Quarter 6 (Summer)	
ME4704 Missile Design ***	
ME/AE4000 level *** (refer to Department Discipline List)	
Electives *	
ME0810 Thesis Research	

***	Required Courses for Missile Systems Engineering Programme
*	Electives can be from any department or you may refer to the suggested list

2.3.1 Suggested Elective Modules for Specialisation Track Weapon Systems Engineering

Suggested Elective Modules For Weapon Systems Engineering Track			Credit
Weapons	ME4700	Weaponeering	3-2
	ME4702	Engineering Systems Risk Benefit Analysis	3-2
	ME4751	Combat Survivability, Reliability, and System Safety	4-1
	PC3172	Physics of Weapon Systems; Fluid Dynamics of Weapons; Shock Waves; Explosions	4-2
	PC3800	Survey of the Effects of Weapons (SE3800)	4-0
	PC4860	Advanced Weapon Concepts	4-1
	PH4171	Physics of Explosives	4-0
	PH4857	Physics of High Velocity Impact, Weapon Lethality, and Survivability	4-0
	PH4911	Simulation of Physical and Weapon Systems	3-2
	ME3750	Platform Survivability	4-0
	ME3780	Introduction to Micro Electro Mechanical Systems Design	3-3
	PH4209	EO/IR systems and Countermeasures	3-2
	PH4273	Physics of Advance Imaging Systems	4-2
Controls	ME3801	Autonomous Systems and Vehicle Control I	3-2
	ME4811	Autonomous Systems and Vehicle Control II	3-2
	ME4821	Marine Navigation	3-2
	ME4823	Dynamics of Autonomous Vehicles	4-0
Thermal/ Fluids	ME3150	Heat Transfer	4-1
	ME3201	Applied Fluid Mechanics	4-1
	ME3240	Marine Power and Propulsion	4-2
	ME3450	Computational Methods in Mechanical Engineering	3-2
	ME4162	Convection Heat Transfer	4-0
	ME4220	Viscous Flow	4-0
	ME4225	CFD and Heat Transfer	3-2
Structural/ Vibration	ME3521	Mechanical Vibrations	3-2
	ME3611	Mechanics of Solids	4-0
	ME4522	Finite Element Methods in Structural Dynamics	4-0
	ME4525	Naval Ship Shock Design and Analysis	4-0
	ME4550	Random Vibrations and Spectral Analysis	3-2
	ME4612	Advanced Mechanics of Solids	4-0
	ME4613	Finite Element Methods	4-0
Others	OA4602	Joint Campaign Analysis	4-0
	OA4603	Test and Evaluation	4-0

2.4 Suggested Matrix for Specialisation Track Autonomous Systems Engineering

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

- The final course in this sequence, Unmanned Systems Design, is a capstone course that integrates the material into a design of (a component of) an autonomous underwater, surface, ground, aerial, or space system, its algorithm or sensor to be tested within the tactical network environment during quarterly field experiments at Camp Roberts Training Site.
- The SE3201/2/3 course sequence is the Integrated Project. All TDSI students must complete this sequence with satisfactory results as part of the MDTS degree requirement.
- Students will have to attend Department seminars, colloquium and introduction to graduate research that are scheduled by the Department.

2	Department	NPS Degree
	Mechanical & Aerospace Engineering	Master of Science in Mechanical Engineering OR Master of Science in Engineering Science (Mechanical Engineering) **Non-ABET Accredited Degree*

Specialisation Track	Autonomous Systems Engineering • Pre-requisite Modules: NIL • Other Specific Skills Needed: Must have BSME or Equivalent for MSME

Quarter 3 (Fall)	
AE2440 Introduction to Digital Computation **	Integrated Project SE3201 Eng. Systems Conceptualization
EC4310 Fundamentals of Robotics **	
AE4860 Space Control **	
ME2801 Introduction to Control Systems **	
ME1810 Thesis Proposal Preparation	
Quarter 4 (Winter)	
ME4811 Multivariable Control of Ship Systems ***	Integrated Project SE3202 Eng. Systems Design
ME3801 Dynamics and Control of Marine and Autonomous Vehicles I **	
ME3720 Introduction to Unmanned Systems **	
ME0951 MAE Seminars	
ME0810 Thesis Research	
Quarter 5 (Spring)	
ME4823 Cooperative Control of Multiple Marine Autonomous Vehicles ***	Integrated Project SE3203 Eng. Systems Implementation
ME4703 (EC4330) Missile Flight and Control **	
ME0951 MAE Seminars	
ME0810 Thesis Research	
Quarter 6 (Summer)	
ME4821 Marine Navigation ***	
CS4330 Introduction to Computer Vision **	
Electives *	
ME0810 Thesis Research	

***	Required courses for Department Discipline Requirement (Overlap with programme requirement)
**	Required courses for Autonomous Systems Engineering programme
*	Electives can be from any department

3. MDTS Specialised Curriculum

Department of Computer Sciences

3	Department	NPS Degree	Suggested Matrix
	Department of Computer Sciences	Master of Science in Computer Science Master of Science in Modelling, Virtual Environments & Simulation	• Cyber Security and Defence • Modelling, Virtual Environments & Simulation (MOVES)

3.1 Degree Requirement

The Master of Science in Computer Science requires students to complete 40 graduate-level credit hours, of which at least 12 credit hours must be at the 4000 level. At least 28 of the 40 graduate-level credit hours listed above must be Cyber Security or MOVES courses.

3.2 Suggested Matrix for Specialisation Track Cyber Security and Defence

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

3	Department	NPS Degree
	Department of Computer Sciences	Master of Science in Computer Science
Specialisation Track	• Cyber Security and Defence • Pre-requisite Modules**: - CS3600 Introduction to Computer Security - CS3310 Artificial Intelligence - CS3502 Computer Comms & Networks - CS3101 Theory of Formal Languages and Automata	

Quarter 3 (Fall)	
CS3101 Theory of Formal Languages & Automata ** CS3690 Network Security *** CS3670 Secure Mgmt of Systems *** CS4900 Technology & Transform.	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
CS4684 Cyber Security Incident Response and Recovery*** Electives * CS4903 Research Methods in CS CS0810 Thesis Research	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
CS4600 Secure Computer Principles *** CS4558 Network Traffic Analysis *** CS4924 Emerging Topics CS0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
CY4700 Applied Defensive Cyberspace Operations *** CS4650 Fundamentals of Info Sys Security Eng *** CS4924 Emerging Topics CS0810 Thesis Research	

***	Required Courses for Cyber Security and Defence programme
**	Required Pre-Requisite Courses: To ensure a sufficient breadth across the field of Computer Science, the course topics must be satisfied as part of the course of study for the MS CS degree. Students who have not taken courses in one or more of these topics during their undergraduate degree program, immediately prior to arriving to NPS, must take or validate the appropriate course(s) at NPS.
*	Electives. Students will coordinate with their Thesis Advisor to choose one (1) advanced CS elective CS course (4000-level) that best augments their thesis research. Acceptance of this course by the Thesis Advisor will be demonstrated by his/her approval of the CS Graduation Checklist.

3.3 Suggested Matrix for Specialisation Track Modelling, Virtual Environments & Simulation

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

3	Department	NPS Degree
	Department of Computer Sciences	Master of Science in Modelling, Virtual Environments & Simulation
Specialisation Track	**Modelling, Virtual Environments & Simulation (MOVES)** • Pre-requisite Modules: - JAVA Programming and/or C++ Programming - Probability and Statistics - OA3103 Data Analysis	

Quarter 3 (Fall)	
CS3310 Artificial Intelligence ***	Integrated Project SE3201 Eng. Systems Conceptualization
MV4001 Human Factors of Virtual Environments **	
MV3500 Internetwork Comm and Simulation **	
MV2921 Introduction to MOVES	
Quarter 4 (Winter)	
MV3202 Computer Graphics Programming **	Integrated Project SE3202 Eng. Systems Design
MV4002 Simulation and Training **	
MV4503 Simulation Interoperability Practicum **	
MV3922 Introduction to Virtual Environment Technology **	
Quarter 5 (Spring)	
MV3203 Graphical Simulation **	Integrated Project SE3203 Eng. Systems Implementation
MV4460 Management of M&S Development **	
MV3923 Introduction to Research in MOVES	
ME0810 Thesis Research	
Quarter 6 (Summer)	
Elective *	
Elective *	
MV4924 Emerging Topics	
MV0810 Thesis Research	

***	Required Courses for Department of Computer Science
**	Required Courses for MOVES
*	Electives. Refer to list of electives.

3.3.1 List of Electives

Students must select two of the following track electives, as available:

		Credit
MV-4025	Cognitive and Behavioural Modeling for Simulations	(3-2)
MV-4657	Modeling and Simulation for STTR Operations	(3-2)
OS-3311	Probability Models for Military Simulations	(4-0)

4. MDTS Specialised Curriculum

Department of Operations Research

4	Department	NPS Degree	Suggested Matrix
	Department of Operations Research	Master of Science in Operations Research	Operations Research

4.1. Degree Requirement

The Master of Science in Operations Research degree requires students to complete a minimum of 40 graduate-level credit. 20 credit-hours must be 4000-level courses, of which at least 16 credit-hours are OA.

4.2. Suggested Matrix for Specialisation Track Operations Research

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

4	Department	NPS Degree
	Department of Operations Research	Master of Science in Operations Research
Specialisation Track	**Operations Research** • Pre-requisite Modules: - MA3042 Linear Algebra, - MA1115 Calculus, - OA3101 Probability, - OA3102 Statistics, - MA3110 Intermediate Analysis, Object Oriented Language	

Quarter 3 (Fall)	
OA3302 Simulation Modelling** OA3103 Data Analysis** OA4603 Test & Evaluation** OA3900 Workshop in Operations Research	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
OA3201 Linear Programming** OA3301 Stochastic Models I ** OA4106 Advanced Data Analysis ***	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
OA4202 Network Flows and Graphs*** OA4301 Stochastic Models II** OA0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
OA4201 Non-Linear Programming *** OA4702 Cost Estimation*** OA4602 Joint Campaign Analysis OA0810 Thesis Research	

***	Suggested level 4000 courses to meet degree requirements
**	Suggested courses

5	Department	NPS Degree	Suggested Matrix
	Department of Physics	Master of Science in Applied Physics Master of Science in Combat Systems Technology	• Free Electron Lasers • Sensor Systems Engineering – General Sensors

5.1. Degree Requirement

5.1.1. Degree requirement for Master of Science in Applied Physics

- The Master of Science in Applied Physics requires students to complete At least 32 credit hours of graduate level courses in physics, mathematics, and engineering including 20 at the 4000 level. Of these 32 hours, at least 20 will be physics courses including 12 at the 4000 level.

- At least one graduate level course in each of the following areas: mechanics, electromagnetism, and quantum physics. Students will demonstrate additional breadth by taking at least one 4000 level physics course outside their concentration area.

- An area of concentration containing a four-course sequence of graduate-level courses in addition to the above requirements, at least two at the 4000 level, in an area related to applied physics.

5.1.2. Degree requirement for Master of Science in Combat Systems Technology

- A Master of Science in Combat Systems Technology requires students to complete a minimum of 32 credit hours of graduate work in physics, mathematics, and engineering, with at least 18 credit hours at the 4000 level. Included in these hours must be at least 20 credit hours of graduate-level physics, including 12 credit hours at the 4000 level.

- Two approved sequences of courses related to combat systems technology. Each sequence must consist of at least four graduate-level courses with at least two courses at the 4000 level. A list of approved sequences is available from the Chairman.

5.2. Suggested Matrix for Specialisation Track Free Electron Lasers

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

5	Department	NPS Degree
	Department of Physics	Master of Science in Applied Physics
Specialisation Track	**Free Electron Lasers** • Pre-requisite Modules: NIL	

Quarter 3 (Fall)	
PH3991 Theoretical Physics ***	Integrated Project SE3201 Eng. Systems Conceptualization
PH4858 Weapon Lethality and survivability **	
PC3200 Physics of Electromagnetic Sensors and Photonic Devices **	
PH3996 Special Topic: Physical Computations with Matlab	
Quarter 4 (Winter)	
PH4911 Simulation of Physical and Weapons Systems **	Integrated Project SE3202 Eng. Systems Design
Elective*	
PH2652 Modern Physics	
PH0810 Thesis Research	
Quarter 5 (Spring)	
PH3152 Particle Mechanics ***	Integrated Project SE3203 Eng. Systems Implementation
PH3360 Electro Magnetic Waves ***	
Elective*	
OA0810 Thesis Research	
Quarter 6 (Summer)	
PH4656 Quantum Mechanics ***	
PH4001 Thesis Presentation and Defence	
Elective*	
PH0810 Thesis Research	

***	Required Courses for Applied Physics
**	Required Courses for Free Electron Lasers
*	Electives
	Support Modules

5.3. Suggested Matrix for Specialisation Track Sensor Systems Engineering – General Sensors

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

5	Department	NPS Degree
	Department of Physics	Master of Science in Combat Systems Technology

Specialisation Track	Sensor Systems Engineering – General Sensors • Pre-requisite Modules: - MA1115 Calculus - MA2121 Differential Equations - PH1623 Optics Electricity & Magnetism

Quarter 3 (Fall)	
PH4858 Electric Ship Weapons Systems*** PH3451 Fundamental Acoustics*** PH3360 Electromagnetic Wave Propagation*** Electives *	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
PH3452 Underwater Acoustics*** Electives* PH2001 Research Topics in Physics	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
PH4857 Physics of High Velocity Impact, Weapon Lethality and Survivability*** Electives* PH0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
PH4272 Laser, Optoelectronics and Electro-Optics II*** PH4001 Thesis Presentation and Defence *** PH0810 Thesis Research	

***	Required Courses for Combat Systems Technology programme
*	Electives
	Support Modules

5.3.1. List of Electives

Students are required to select one from each serial number

S/N	Courses	Credit	Courses	Credit
1	PH3991 Theoretical Physics	(4-2)	PH4271 Lasers, Optoelectronics & Electro-Optics I	(4-1)
2	PH3280 Introduction to MEMS Design	(3-3)	PH4454 Sonar Transducer Theory and Design (or Equivalent)	(4-2)
3	PH3052 Physics of Space and Airborne Sensor Systems	(3-2)	EC4450 Sonar Systems Engineering	(4-1)
4	PH3292 Applied Optics	(4-2)	PH3655 Solid State Physics	(4-0)
5	PC4860 Advanced Weapons Concepts	(4-1)	PH4455 Sound Propagation in Ocean	(4-0)

6. MDTS Specialised Curriculum

6	Department	NPS Degree	Suggested Matrix
	Department of Oceanography	Master of Science in Physical Oceanography	• Operational Oceanography • Undersea Warfare NEW!

6.1. Degree Requirement

A Master of Science in Physical Oceanography requires at least 32 credit hours of approved graduate study, of which must include at least eight physical oceanography courses with at least four courses in the OC4000 series totalling 28 credit hours, and of the 28 credit hours at least 13.5 credit hours must be at the 4000 level in courses other than directed study. Four credit hours of directed study or additional OC elective courses would count for the remainder of the degree requirements.

6.2. Suggested Matrix for Specialisation Track Operational Oceanography

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

6	Department	NPS Degree
	Department of Oceanography	Master of Science in Physical Oceanography
Specialisation Track: Operational Oceanography • Pre-requisite Modules: - MA1115 Multiple-Variable Calculus - MA2043 Matrix Algebra		- MA1116 Vector Calculus - MA2121Ordinary Differential Equations - MA3132 Partial Differential Equations - Fourier Series and Transforms

Quarter 3 (Fall)	
OC3230 Descriptive Physical Oceanography** OC3321 Air-Ocean Fluid dynamics** OC3260 Fundamentals of Ocean Acoustics** OC4900 Directed Studies on Oceanography**	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
MR/OC3140 Probability and Statistics for Air-Ocean Science** MR/OC2030 MATLAB** OC3240 Ocean Circulation Analysis** OC0810 Thesis Research	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
OC4211 Ocean Dynamics II** OC3150 Analysis of Ocean Time Series** OC4210 Littoral Field Studies** OC0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
OC4271 Tactical Oceanography** Elective (OC 4000 level)* OC0810 Thesis Research OC0999 Thesis Presentation	

**	Required Courses for Physical Oceanography programme
*	Elective

6.3. Suggested Matrix for Specialisation Track Undersea Warfare

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

6	Department	NPS Degree
	Department of Oceanography	Master of Science in Physical Oceanography

Specialisation Track	Undersea Warfare • Pre-requisite Modules: NIL

Quarter 3 (Fall)	
PH3991 Theoretical Physics *** PH3451 Fundamental Acoustics*** EO3402 Signals and Noise*** UW0001 Seminar Elective*	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
PH3452 Underwater Acoustics*** PH4454 Sonar Transducer Theory and Design*** EC4450 Sonar Systems Engineering*** UW0001 Seminar Elective*	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
PH4455 Sound Propagation in the Ocean*** UW0001 Seminar Elective* PH0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
UW2001 History of USW Part I Mine Warfare*** UW2002 History of USW Part II Yesterday, Today, Tomorrow*** UW0001 Seminar Elective* PH0810 Thesis Research	

***	Required Courses for Undersea Warfare
*	Electives
	Support Modules

6.3.1. List of Electives

Courses	Credit	Courses	Credit
PH3002 Non-Acoustics Sensor Systems	(4-0)	PH3996 Special Topic in Intermediate Physics (MATLAB)	(3-0)
OC3230 Descriptive Physical Oceanography	(3-1)	ME3720 Introduction to Unmanned Systems	(3-2)
EC3460 Introduction to Machine Learning for Signal Analytics	(3-2)	OA3602 Search Theory and Detection	(4-0)

7. MDTS Specialised Curriculum

7	Department	NPS Degree	Suggested Matrix
	Department of Applied Mathematics	Master of Science in Applied Mathematics	Applied Mathematics and Certificate in Network Science or Certificate in Secure Communications

7.1. Degree Requirement

- The Master of Science in Applied Mathematics requires student to complete a minimum of 32 graduate level credit hours (level 3000-4000 courses) with a minimum QPR of 3.0.
- The program must include at least 16 credit hours in 3000-level mathematics courses and 16 credit hours of approved 4000-level mathematics courses.
- In addition to the core courses required, the program allows the student to select electives leading to a certification in Network Science or Secure Communications.

7.2. Suggested Matrix for Specialisation Track Applied Mathematics

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/4cademics/GeneralCatalog/Layout.html

7	Department	NPS Degree
	Department of Applied Mathematics	Master of Science in Applied Mathematics and Certificate in Network Science or Certificate in Secure Communications

Specialisation Track: Applied Mathematics	
• Pre-requisite Modules: - MA1115 / MA1116 Multiple-Variable Calculus & Vector Calculus	- MA 2025 Discrete Mathematics - MA 2043 Matrix & Linear Algebra, - MA2121 Differential Equations

Course	Integrated Project
Quarter 3 (Fall)	
MA3042 Linear Algebra ***	Integrated Project SE3201 Eng. Systems Conceptualization
MA4027 Graph Theory ***	
MA3025 Logic and Discrete Mathematics II ***	
Network Science or Secure Communications Course **	
Quarter 4 (Winter)	
MA3560 Modern Algebra and Number Theory ***	Integrated Project SE3202 Eng. Systems Design
Network Science or Secure Communications Course **	
Elective (MA/CS/ 4/3xxx)*	
MA0810 Thesis Research	
Quarter 5 (Spring)	
MA 4570 Cryptography ***	Integrated Project SE3203 Eng. Systems Implementation
NW or SC Course **	
MA0810 Thesis Research	
Quarter 6 (Summer)	
MA3607 Real Analysis ***	
MA 4560 Coding and Information Theory ***	
MA0810 Thesis Research	

***	Required Courses for Applied Mathematics programme
**	Required Courses for Network Science or Secure Communications certification
*	Elective (Network Science or Secure Communications)

7.2.1. Suggested Elective Modules for Certification in Network Science

Courses		Credit
MA 4550	Boolean Functions ***	(4-0)
MA3046	Matrix Analysis ***	(4-1)
MA4404	Complex Networks ***	(4-0)
MA4400	Cooperation and Competition	(4-0)
CS4558	Network Traffic Analysis	(3-2)
OA4202	Network Flows	(4-0)

7.2.2. Suggested Elective Modules for Certification in Secure Communications

Courses		Credit
MA4026	Combinatorial Mathematics ***	(4-0)
MA/CS/ 4/3xxx	*Select 2 courses*	

8	Department	NPS Degree	Suggested Matrix
	Department of Systems Engineering	Master of Science in Systems Engineering (MS SE) OR Master of Science in Engineering Systems (MS ES)**Non-ABET Accredited Degree*	Systems Engineering

8.1. Degree Requirement

The Master of Science in Systems Engineering or Master of Science in Engineering Systems requires students to complete 36 hours of graduate level course, with at least 16 at the 4000 level. Completion of Systems Engineering Core course sequences and completion of a thesis.

8.2. Suggested Matrix for Specialisation Track Systems Engineering

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

8	Department	NPS Degree
	Department of Systems Engineering	Master of Science in Systems Engineering (MS SE) OR Master of Science in Engineering Systems (MS ES)* **Non-ABET Accredited Degree*
Specialisation Track		Systems Engineering • Pre-requisite Modules: - OS3180 Probability and Statistics for Systems Engineering - AE2440 Introduction to Digital Computation

Quarter 3 (Fall)	
SE3100 Fundamentals of Systems Engineering ** Electives	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
SE3011 Engineering Economics and Cost Estimation ** SE3250 Capability Engineering ** SI3400 Engineering Project Management ** Electives	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
SE3302 System Suitability ** OS4680 Naval Systems Analysis ** SE4150 Systems Architecture and Design ** Electives SE0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
OA4603 Systems Test & Evaluation ** SE4115 Combat Systems Integration ** Electives SE0810 Thesis Research	

**	Required Courses for Systems Engineering programme
*	Electives

8.2.1. Suggested Elective Modules for Specialisation Track Systems Engineering

> *The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.*
> ***For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html***

Courses		Credit
SE3112	Combat Systems I – Introduction to Sensors	(4-2)
SE4003	Software Systems Engineering	(3-2)
SE4353	Risk Analysis & Management	(3-2)
OS3401	Human Factors in Systems Design	(3-1)
SE3113	Combat Systems II – Conventional Weapons	(4-2)
OS3401	Human Factors in Systems Design	(3-1)
SE4112	Combat Systems Engineering III	(4-2)
ME4751	Combat Survivability, Reliability and Systems Safety Engineering	(4-1)

Modules on "Management and Systems Acquisition" are available as Electives. Please work with the NPS Academic Associate and Program Officer for actual courses.

9. MDTS Specialised Curriculum

Department of Systems Engineering and Department of Operations Research

	Department	NPS Degree	Suggested Matrix
9	**Department of Systems Engineering and Department of Operations Research**	Master of Science in Systems Engineering Analysis	Systems Engineering Analysis

9.1. Degree Requirement

- The Systems Engineering and Operations Research Departments jointly award the Master of Science in Systems Engineering Analysis (MS SEA) degree.

- The candidate must take all courses in an approved study program, which must also satisfy the following requirements:
  - A minimum of 36 credit hours of credit in 3000 and 4000 level courses, including a minimum of 12 credit hours at the 4000 level.
  - Participation in a capstone project with a minimum of 12 credits is required for the degree.

9.2. Suggested Matrix for Specialisation Track Systems Engineering Analysis

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

9	Department	NPS Degree
	Department of Systems Engineering and Department of Operations Research	Master of Science in Systems Engineering Analysis

Specialisation Track	Systems Engineering Analysis • Pre-requisite Modules: - OS3180 Probability and Statistics for Systems Engineering

Quarter 3 (Fall)	
SE3100 Fundamentals of Systems Engineering ***	Integrated Project SE3201 Eng. Systems Conceptualization
OS 4680 Naval Systems Analysis **	
Electives * (Overload)	
SE3000 SE Colloquium	
Quarter 4 (Winter)	
SI3400 Engineering Project Management ***	Integrated Project SE3202 Eng. Systems Design
OS3680 Naval Tactical Analysis **	
OS3211 Systems Optimization **	
Electives * (Overload)	
SE3000 SE Colloquium	
Quarter 5 (Spring)	
SE3302 System Suitability ***	Integrated Project SE3203 Eng. Systems Implementation
SE4150 Systems Architecture and Design ***	
OS3380 Combat Systems Simulation **	
Electives *(Overload)	
SE3000 SE Colloquium	
Quarter 6 (Summer)	
SE4354/OA4603 Systems Test & Evaluation ***	
SE4115 Combat Systems Integration ***	
OA4702 Cost Estimation **	
OA4602 Joint Campaign Analysis **	
SE3000 SE Colloquium	

***	Required Courses for Systems Engineering
**	Required Courses for SEA
*	Electives (Overloading) Refer to suggested list below

9.2.1. Suggested Elective Modules for Specialisation Track Systems Engineering Analysis

Courses	
OA3411	Introduction to Human Systems Integration
SE4353	Risk Analysis & Management
OS3401	Human Factors in Systems Design
ME4751	Combat Survivability, Reliability and Systems Safety Engineering
SE3113	Combat Systems II – Conventional Weapons
OS3401	Human Factors in Systems Design
SE4112	Combat Systems III - Sensor Systems Engineering

10	Department	NPS Degree	Suggested Matrix
	Space Systems Academic Group	Master of Science in Astronautical Engineering OR Master of Science in Engineering Science (Astronautical Engineering)* **Non-ABET Accredited Degree* Master of Science in Space Systems Operations	• Space Systems Engineering • Space Systems Operations

10.1. Degree Requirement

10.1.1. Degree requirement for Space Systems Engineering

- A Master of Science in Astronautical Engineering or Master of Science in Engineering Science (Astronautical Engineering) requires students to complete a minimum of 48 credit hours of graduate level work.

- The student must take all courses in an approved study program, which must satisfy the following requirements:
  - There must be a minimum of 32 credit hours of credits in 3000 and 4000 level courses, including a minimum of 12 credit hours at the 4000 level.
  - Of the 32 credit hours, at least 24 credit hours must be in courses offered by the MAE Department.

10.1.2. Degree requirement for Space Systems Operations

- A Master of Science in Space Systems Operations requires students to complete a minimum of 32 credit-hours of graduate level work is required, of which at least 15 hours must be at the 4000 level.

- Graduate courses in at least four different subject areas must be included and in two areas, a course at the 4000 level must be included. There is also a requirement of three courses constituting advanced study in an area of specialization.

10.2. Suggested Matrix for Specialisation Track Space Systems Engineering

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

10	Department	NPS Degree
	Space Systems Academic Group	Master of Science in Astronautical Engineering OR Master of Science in Engineering Science (Astronautical Engineering)

Specialisation Track	Space Systems Engineering
	• Pre-requisite Modules: - Matrix & Linear Algebra, Matrix Analysis, Differential Equations, Multi Variable Calculus, Statics, Dynamics, Electricity & Magnetism, Physics, Dynamics and Controls, MatLab and Simulink

Quarter 3 (Fall)	
AE2820 Intro to Spacecraft Structures ***	Integrated Project SE3201 Eng. Systems Conceptualization
AE4850 Astrodynamic Optimization ***	
AE3804 Thermal Control of Spacecraft ***	
AE3818 Spacecraft Attitude Determination & Control ***	
Quarter 4 (Winter)	
PH2514 Space Environment ***	Integrated Project SE3202 Eng. Systems Design
ME3521 Mechanical Vibrations ***	
SS3500 Orbital Mechanics and Launch Systems	
SS0810 Thesis Research	
Quarter 5 (Spring)	
AE4870 Spacecraft Design 1***	Integrated Project SE3203 Eng. Systems Implementation
AE3830 Spacecraft guidance & Control ***	
AE4820 Advanced & Multibody Mechanics ***	
SS0810 Thesis Research	
Quarter 6 (Summer)	
AE3851 Spacecraft Propulsion ***	
EO3525 Communications Engineering ***	
SE0810 Thesis Research	

*** Required Courses for Space Systems Engineering programme

10.3. Suggested Matrix for Specialisation Track Space Systems Operations

The suggested matrix below is provided as a guide only. Please work with the NPS Academic Associate and Program Officer for detailed course availability in each quarter.
For full listing, refer to http://www.nps.edu/Academics/GeneralCatalog/Layout.html

10	Department	NPS Degree
	Space Systems Academic Group	Master of Science in Space Systems Operations

Specialisation Track	Space Systems Operations • Pre-requisite Modules: - Calculus, Electricity & Magnetism, Physics

Quarter 3 (Fall)	
SS1100 Programming for Space Applications *** SS3011 Space Technology & Applications ***	Integrated Project SE3201 Eng. Systems Conceptualization
Quarter 4 (Winter)	
NS4677 Space and International Security *** SS3400 Orbital Mechanics & Launch Systems *** PH3052 Remote Sensing SS0810 Thesis Research	Integrated Project SE3202 Eng. Systems Design
Quarter 5 (Spring)	
AE4830 Spacecraft Systems 1 *** PH2514 Space Environment *** SS3600 Space Systems Modeling & Simulation *** SS0810 Thesis Research	Integrated Project SE3203 Eng. Systems Implementation
Quarter 6 (Summer)	
IS3502 Network Operations 1*** AE4831 Spacecraft Systems 2 *** SS4xxx 4000 level Elective * SS0810 Thesis Research	

***	Required Courses for Space Systems Operations programme
*	Elective

MDTS Common Curriculum
Course Description

Engineering Mathematics (Online Refresher Module)
- Introduction to vector fields, vector algebra and partial derivatives of vector and scalar fields.
- Gradient, divergence and curl.
- Introduction to line, surface and volume integrals; Green's Divergence.
- ODE classification and general solutions.
- First and second-order homogeneous and non-homogeneous ODEs.
- Introduction to error and sensitivity analyses.
- Matrix algebra: introduction and notation; rank, determinants, transpose and inverse; simple elementary row operations and linear independence; eigenvalues and eigenvectors.
- Complex numbers: introduction and geometrical representation; Argand diagram; complex algebra; Euler's representation and De Moivre's theorem.
- Fourier analysis: concept of transforms; Fourier series and orthogonality relations; Fourier transforms and applications.
- Probability axioms and event probability.
- Random variables and their probability distributions.
- Hypothesis testing, conditional probability and expectation.

Probability & Statistics (Online Refresher Module)
Topics include:
- Descriptive Statistics
- Probability Concepts
- Conditional Probability
- Discrete Distribution
- Continuous Distribution, Non-normal, Multivariate

DTS5701 Large Scale Systems Engineering
Large Scale Systems Engineering deals with the complexities of large-scale systems. The Systems Approach and Systems Engineering methodologies are used to understand and conceptualize the key issues in the planning, design and management of large scale systems.

The module aims to help students learn about Large Scale Systems Engineering (LSSE) with theories, stories and case studies on how systems are planned and implemented.

By the end of the module, students are expected to be able to analyse and synthesise systems and design large-scale projects using the LSSE framework taking into consideration their goals, boundaries, stakeholders, complexities, trade-offs, risks and unintended consequences.

DTS5702 C3 Systems
This module provides the key underlying principles and concepts of C3 engineering and their application in the design, development and integration of C3 systems in modern armed forces.

Using a systems engineering approach, the module will also enable participants to have a good appreciation of the key considerations and challenges as well as good engineering practices associated with C3 design and integration with sensor and weapon systems.
Topics related to emerging trends, concepts and technologies will also be covered.

DTS5703 Operations Research
This is an introductory module to operations research which will cover both deterministic and stochastic models for effective decision-making.

Topics include Mathematical programming (overview on models building and sensitivity analysis; computer-based solutions), multi-criteria decision analysis, reliability and maintenance, queueing theory and simulation. Relevant cases on military applications will be discussed.

DTS5731 Fundamentals of Systems Engineering (Online Module)
This module is an introductory module providing an overview of the topic and a flavour of the details which should be more fully explored in depth through other modules. It explains systems, systems engineering, lifecycles, associated activities, products, applications, processes, models, methods and strategies.

DTS5732 Artificial Intelligence and Data Analytics
This is an introductory module to artificial intelligence (AI) and data analytics (DA). It covers various topics of AI and DA.

The AI topics include heuristic search, constraint satisfaction, logic and inference, and natural language processing. The DA topics include data pre-processing, data visualization, classification, model evaluation, decision trees, neural networks, deep learning, association analysis, and clustering.

DTS5733 Sensors & Intelligence
This module introduces sensor and intelligence technologies and their applications in the operational context. It focuses mainly on the most commonly deployed sensor technologies such as Radar and Electro-Optical (EO) sensors as well as established and emerging intelligence areas such as communications intelligence (COMINT), electronic intelligent (ELINT) and Open-Source Intelligence (OSINT).

The underlying technical principles for performance assessments in various environments, such as electronic warfare and design trade-offs will be covered and reinforced through the use of application examples.

DTS5734 Guided Systems
The module covers the principles, technologies and operational aspects of smart weapon systems e.g. guided weapons, precision munitions and unmanned vehicles (UxVs).

The interplay of various sub-systems for target identification & tracking, guidance/navigation, command and control and their impact on mission effectiveness will be examined with consideration of counter-measures and counter-counter-measures. Additional topics include advanced concepts for autonomy, interoperability and teaming and cooperation. The course will include case studies of these weapon systems in actual combat.

DTS5735 Cybersecurity
This module introduces cybersecurity concepts and their applications. It aims to illustrate how systems can fail under malicious activities, and how the threats can be mitigated and managed.

Topics include cryptography, communication channel security, system security, trusted computing, policy making, human factors, etc. Applications such as cloud security, IOT security, security operations centre, AI in cybersecurity, and case studies on well-known attacks will be used to reinforce the learning of various foundational concepts.

DTS5736 Systems Design Project

The purpose of this module is to allow students to practise Systems Engineering Applications in realistic large scale defence/security problem solving.

Students are required to adopt the systems approach in problem definition/framing and applying various technical disciplines taught in this programme, e.g. C3, Sensors and Intelligence, DA/AI, Guided Weapons, Unmanned Systems, Cyber, Operations Research etc., in developing the system solutions. They are expected to conduct systems engineering studies to formulate and synthesize sound and cost effective systems solutions to address the operational requirements and scenario.

Specialised Curriculum

Module Description

Module descriptions are extracted from: http://www.nps.edu/Academics/GeneralCatalog/Layout.html

1 Department of Electrical & Computer Engineering

Other Possible Specialty Combinations

- Communication Systems and Sensor Engineering (Electronic Warfare or Radar Focus)
- Communication Systems and Network Engineering
- Communication Systems and Cyber Systems
- Network Engineering and Sensor Engineering (Electronic Warfare or Radar Focus)
- Network Engineering and Cyber Systems

Communications Systems Specialty

EC3500 Analysis of Random Signals
Fundamental concepts and useful tools for analysing non-deterministic signals and noise in military communication, control and signal processing systems are developed. Topics include properties of random processes, correlation functions, energy and spectral densities, linear systems and mean square estimation, noise models and special processes.

EC3510 Communications Engineering
The influence of noise and interference on the design and selection of hardware in practical communication transmitters and receivers is analysed. Specific topics include link budget analysis and signal-to-noise ratio calculations, receiver noise performance for various modulations schemes, bandwidth trade-offs, and hardware parameters. Examples of military communications systems are included.

EC4550 Digital Communications
This module presents some of the advantages and limitations of modern military M-ary digital communications systems. M-ary modulation formats, matched filter receivers, probability of error calculations, non-coherent receivers, carrier synchronisation, symbol synchronisation, telephone line modems, wideband modems, bandwidth and signal energy, diversity combining and Rayleigh fading channels are covered. Examples of current operational and proposed military space and earth links are treated.

EC4580 Error Correction Coding
Digital military communication systems often employ error control coding to improve effectiveness against noise, fading, and jamming. This course, together with EC4560, provides students the necessary foundations for understanding the principles of such systems. Topics include Shannon's channel capacity theorem and coding methods for error control in digital communications systems, including convolutional, block, concatenated, and turbo codes, as well as trellis-coded modulation. Applications of error control coding to modern digital communications systems are discussed.

EC3600 Antennas and Propagation
A fundamental understanding of antennas, scattering, and propagation is developed. Characteristics and design principles of common antenna types such as dipoles, arrays, horns, reflectors and microstrip patches, are considered. Concepts of antenna gain and effective area are used to develop power link equations. Scattering theory is introduced and propagation phenomena are considered for real-world scenarios. Design applications include phased, Yagi and log-periodic arrays, as well as shaped-beam reflector antennas, sidelobe suppression, radar target scattering, stealth principles, surface waves, HF and satellite communications.

EC3630 Radiowave Propagation
This course treats the effects of the earth and its atmosphere on the propagation of electromagnetic waves at radio frequencies. Topics covered include ground waves, sky waves, ducting, reflection, refraction, diffraction, scattering, attenuation, and fading. Basic theory is covered and computer models are introduced where appropriate. Emphasis is placed on determination of the transmission loss between transmitting and receiving antennas. Computer laboratory exercises are used to illustrate the propagation characteristics of various indoor and outdoor environments, and their effects on system performance.

EC3700 Joint Network-Enabled Electronic Warfare I
The concept of information operations (IO) and the critical role for electronic warfare (EW) are examined. The net-enabled force transformation is presented emphasizing how network-enabled EW technology provides a force multiplier for this transformation. Important EW technology components of SeaPower-21 are emphasized. The network space – battlespace duality and the Global Information Grid are also analyzed (FORCEnet). Metrics are presented to quantify the information value from wireless networks of distributed sensors and weapons. A direct assessment of the value of the network (information superiority) to the combat outcome (battlespace superiority) is presented. Integrated air defense suppression examples are studied using game theory to demonstrate the concepts. The role of intelligence also is emphasized. Sensor technologies and their use in the battlespace are presented. Mathematical models for electronic attack (EA) techniques are developed including those against GPS, RF and IR sensors. Off-board EA techniques including chaff, towed and rocket decoys, and digital image synthesizers are emphasized for counter-surveillance, counter-targeting and counter-terminal. High-power microwave and laser-based directed energy weapons are examined. Sensor protection techniques are discussed including an introduction to the new area of counter-electronic support. Students do a research project on a topic of interest from the Force Transformation Roadmap. Laboratory exercises are also conducted in the Radar and Electronic Warfare Laboratory.

EC4690 Joint Network-Enabled Electronic Warfare II
The course is intended for international students and contains the same material as EC4680. The course continues the discussion of counter electronic support and begins with an introduction to low-probability-of-intercept (LPI) emitter signaling techniques and technologies. The origin and importance of the LPI emitter are emphasized. Case studies are shown to demonstrate the capability of the LPI emitter as an anti-ship capable missile seeker. Network enabled receiver techniques are presented highlighting the benefits of the sensor-shooter-information grid and swarm intelligence. The new challenges facing the intercept receiver design and the trends in receiver technology are addressed. To increase the processing gain of the receiver, time-frequency signal processing methods are presented and include the pseudo Wigner-Ville distribution, quadrature mirror filter bank trees for wavelet decomposition and the Choi-Williams distribution. Bi-frequency techniques are also emphasized and include cyclostationary processing for estimating the spectral correlation density of the intercepted signal. Calculations using each signal processing method are shown to demonstrate the output information and its correlation with the input signal parameters. New detection results are then derived by the student for various LPI signaling schemes to illustrate the parameter extraction methods developed. Autonomous emitter classification architectures are also presented. Laboratory simulation exercises are conducted to demonstrate the concepts.

EC4610 Radar Systems

The radar range equation is developed in a form including signal integration, the effects of target cross-section, fluctuations, and propagation losses. Modern techniques discussed include pulse compression frequency modulated radar, moving target indicator (MTI) and pulse Doppler systems, monopulse tracking systems, multiple unit steerable array radars, and synthetic aperture systems. Laboratory sessions deal with basic pulse radar systems from which the advanced techniques have developed, with pulse compression, and with the measurement of radar cross-section of targets.

Network Engineering Specialty

EC3710 Computer Communication Methods

The course objective is to develop an understanding of computer communications networks with emphasis on the requirements of military environments and the U.S. Navy's combat platforms. Coverage includes the essential topics of network topology, connectivity, queuing delay, message throughput, and performance analysis. The layered network architectures, such as the seven-layer OSI model and DoD's TCP/IP protocol suite, are covered. The techniques and protocols used in these layers are discussed. Local area networking technologies such as Ethernet, FDDI and wireless Ethernet, and wide area technologies such as X.25 and frame relay are covered. Principles of networking devices (hubs, switches, and routers) are presented. Some distributed applications are presented briefly.

EC4725 Advanced Telecommunication Systems Engineering

Studies the engineering of communications transport networks with a particular emphasis on telephony systems. Presents basic concepts in conventional telephony and traffic engineering such as availability, blockage, dimensioning and survivability. Introduces the architecture of Public Switched Telephone Networks (PSTN) and Mobile Switching Networks (MSN). Presents alternatives for enterprise architectures including Private Automatic Branch Exchange (PABX) and Media Gateways (MG). Examines DoN implementations from intra-ship, ship-to-ship and long haul. Discusses approaches to signaling and provisioning. Presents the Signaling System No. 7 (SS7) architecture. Surveys a variety of transport network technologies to include the Synchronous Optical Network (SONET)/Synchronous Digital Hierarchy (SDH) standard, Dense Wavelength Division Multiplexing (DWDM), dark fiber, and metro Ethernet. Introduces carrier-grade Voice-over-Internet Protocol (VoIP) implementations. Concludes with a discussion of Network Management.

EC4745 Mobile Ad Hoc Wireless Networking

The course presents the fundamental principles, design issues, performance analysis, and military applications of infrastructure and ad hoc wireless packet switched networks. Radio wave propagation, wireless channel characteristic, orthogonal frequency division multiplexing, transceiver design, channel coding, and other physical layer technologies are reviewed. Principles of wireless local area and wide area (cellular) networks are presented. Design and performance analysis of medium access control mechanisms - contention, reservation and scheduling - are covered. Mobile IP protocol is presented, and reactive and proactive protocols for routing in ad hoc networks are introduced. The performance of TCP over wireless networks is analyzed. Security in infrastructure and ad hoc networks is addressed. Sensor networks are introduced. Energy management is discussed. The widely used and emerging wireless networking standards are reviewed. Hardware laboratory assignments provide hands-on experience and OPNET projects allow simulation of large scale networks to complement the theory presented in the course.

EC4785 Internet Engineering

This course examines the optimal design and analysis of interconnected, heterogeneous computer networks, specifically those employed by the US Navy (e.g., IT-21). A common theme throughout will be the confluence of connection-oriented and connectionless data communications and their overarching networking methodologies. The course will focus primarily on the TCT/IP suite. Techniques for segmentation and reassembly, routing, transfer agent placement, error control, throughput analysis, broadcasting, and multicasting will be examined in detail. Performance of common distributed applications will be analyzed.

EC3730 Cyber Network and Physical Infrastructures

Cyber infrastructure systems and technologies of interest to the military. Copper and fiber media networks, telecommunication networks and signaling, the Internet, enterprise networks, network-centric sensing, collection, monitoring, dissemination, and distribution of critical data. Terrestrial wireless networks: cellular networks, local area and long haul data networks (GSM, WiFi, WiMAX, LTE, Link 16 and Link 22). Space based networks: satellite communication networks, wide area large sensor networks. Heterogeneous networks: end-la-end communication, sensing, collection, and distribution across fiber, terrestrial wireless, and satellite networks, protocols, design and performance analysis. Control and overlay networks such as Supervisory Control and Data Acquisition (SCADA) systems and the National power grid.

EC3740 Reverse Engineering in Electronic Systems

This course presents fundamental, systems-level concepts for developing an understanding of system functionality without a prior access to the system's design specifications. It considers generalized approaches to developing a set of specifications for a complex system through orderly examination of components of that system. The course illustrates procedures for identifying the system's components and their interrelationships. The course is divided into two parts. The first part focuses on software reverse engineering where students perform elementary reverse engineering on basic programs using assembly language and software disassembly. Topics related to software reverse engineering including obfuscation techniques and malware analysis will be discussed. The second part of the course will focus on hardware reverse engineering by studying integrated circuit (IC) and circuit board analysis using SPICE and black box techniques. Other tools that aid in hardware reverse engineering such as JTAG will be studied in depth. Analysis of reverse engineering using mathematics, including power analysis will also be studied.

EC4730 Covert Communications

Electronic signal and data communication mechanisms in which the presence of a message being transmitted is concealed in plain sight of other signals or data are presented. Information hiding in user data, protocol data, and radio, electronic, acoustic and other sensory signals is examined. The techniques of steganography, covert channels, low probability exploitation, and information concealment in analog signals are studied. Techniques and mechanisms for establishing robust, secure covert communication schemes are introduced. The detection, analysis, and abortion of adverse covert communication schemes are discussed. Design of systems suitable for attack and defense of covert communications using programmable logic devices is introduced. Low probability of detect, low probability of intercept, and anti-jamming techniques are reviewed. Embedding and extraction algorithms of steganography are presented. Related topics of watermarking and embedded malware are reviewed.

EC4770 Wireless Communications Network Security

Examines the impact of the radio frequency environment on the security of wireless communications networks. Specifically, considers access and availability issues related to jamming and associated countermeasures such as spread spectrum transmission. Investigates diversity applications such as Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM). Examines confidentiality assurance in the form of encryption and analyzes the impact of the RF environment on various cipher types such as stream and block ciphers. Discusses approaches to integrity assurance in the form of digital hashing, interleaving, and convolutional coding. Examines all of the above factors in the context of a variety of topologies to include personal area networks (PAN), local area networks (LAN), metropolitan area networks (MAN) and wide area networks (WAN). Provides a brief overview of encryption and digital signaling. Analyzes and compares protocol implementations such as Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA), the WiMax Cipher Block Chaining Message Authentication Code Protocol (CCMP) and the Mobile Application Part (MAP) of Signaling System No. 7 (SS7). Discuss general aspects of wireless communication vulnerabilities.

Specialisation Track: Weapon Systems Engineering (Missile Systems Engineering Programme)

Required Courses

AE4452 Advance Missile Propulsion

Analysis and design of solid propellant rockets, ramjets, dual-combustion ramjets, scramjets and ducted rockets. Propellant selection criteria and characteristics, combustion models and behavior, performance analysis, combustor design, combustion instabilities and damping, mission and flight envelope effects on design requirements and technology requirements. Use of performance and grain design codes (SPP, PEP, and NASA SP233) and laboratory test firings for comparison with measured performance.

ME3205 Missile Aerodynamics

Potential flow, thin-airfoil and finite wing theories. Linearized equations, Ackeret theory, Prandtl-Glauert transformations for subsonic and supersonic wings. Planform effects. Flow about slender bodies of revolution, viscous crossflow theory.

ME4703 Missile Flight and Control

Tactical Missile Flight Dynamics, Guidance and Control. Kinematics and dynamics of motion, forces and moments acting on the missile, coordinate frames and transformations, concepts of stability and control. Key principles of feedback control. Stability and performance specifications, Concept of controllability, PID control. Lateral autopilot design, classical and modern design approaches; agility in maneuvering trajectories. Homing loop design, operational requirements. Principles of missile guidance as a control task; stability of guidance laws. Pursuit guidance equation, constraints, and the associated performance specifications; firing envelope, "no-escape envelope." Proportional navigation guidance law, stability and performance specifications of PN guidance. Metrics of objective comparison of guidance laws and their applicability in specific scenarios of engagement. Additional topics are selected from the following areas to address the general interests of the class: advanced guidance laws, passive sensors, INS guidance, fire control and tracking systems.

ME4704 Missile Design

Conceptual missile design methodology centered around a student team design project, focused on a military need defined by a Request-for-Proposal. It stresses the application aerodynamics, propulsion, flight mechanics, cost, supportability, stability and control and provides the student with their application to design. Consideration is given to trade-offs among propulsion requirements, air loads, quality sensors, guidance laws, quality, controls, and structural components.

Suggested Electives

ME3450 Computational Methods in Mechanical Engineering

The course introduces students to the basic methods of numerical modeling for typical physical problems encountered in solid mechanics and the thermal/fluid sciences. Problems that can be solved analytically will be chosen initially and solutions will be obtained by appropriate discrete methods. Basic concepts in numerical methods, such as convergence, stability and accuracy, will be introduced. Various computational tools will then be applied to more complex problems, with emphasis on finite element and finite difference methods, finite volume techniques, boundary element methods and gridless Lagrangian methods. Methods of modeling convective non-linearities, such as upwind differencing and the Simpler method, will be introduced. Discussion and structural mechanics, internal and external fluid flows, and conduction and convection heat transfer. Steady state, transient and eigenvalue problems will be addressed.

PH3204 Electro-Optic Principles and Devices

This course provides the basic physical principles applicable to air-borne and water-borne missiles, as well as the fluid dynamics of shocks and explosions. Topics include: Elements of thermodynamics, ideal fluid flow, elementary viscous flows, similitude and scaling laws, laminar and turbulent boundary layers, underwater vehicles, classical airfoil theory, supersonic flow, drag and lift of supersonic airfoils with applications to missiles, fluid dynamics of combustion, underwater explosions.

OA4603 Test Evaluation

This course is designed to cover Developmental and Operational Test and Evaluation and Military Experimentation, including statistical concepts and methods frequently used in weapon system testing and experimentation environments. The course is taught from the perspective of the Program Manager, Test Project Officer, Test Engineer, Test Analyst, and Statistician. A number of actual military cases are used for examples. Topics include the Role of Test and Evaluation in Systems Engineering and Acquisition Management, Test Planning and Design, Development of Measures of Effectiveness and Measures of Performance, Conduct of Tests, Data Analysis, and Reporting of Test Results. A detailed group test planning project and design exercise are included. Upon successful completion of this course, students receive DAWIA Level II and Level III Intermediate and Advanced Test and Evaluation certification.

Specialisation Track: Autonomous Systems Engineering

Required Courses

ME4811 Multivariable Control of Ship Systems
This course takes students through each stage involved in the design, modeling and testing of an unmanned system. The course is built around the creation of a fully functional command and control system for a typical robotic platform, e.g., unmanned aerial vehicle (UAV), unmanned surface vehicle (USV) or unmanned underwater vehicle (UUV). Students are presented with a challenge for applying unmanned systems to an authentic scenario of naval significance. Students are then guided through development of equations of motion, control design and system performance in the context of solving a real-world problem. Final designs are evaluated in a combination of simulation and experimental environments as appropriate.

ME4823 - Cooperative Control of Multiple Marine Autonomous Vehicles (4 - 0)
This course takes students through each stage involved in the design, modeling and evaluation of a multi-robot solutions to current and future naval challenges. The course provides students with an overview of the state-of-the-art in multi-robot control and the theoretical building blocks common to these methods. Students are presented with an authentic multi-robot control challenge which serves as the focus of the remainder of the course. Students are guided through a selection process to formulate multi-robot control techniques appropriate to the specific application. The course culminates with implementation of multi-robot control (in simulation and/or experiment) to quantitatively evaluate performance of student designs.

ME4821 Marine Navigation
This course presents the fundamentals of inertial navigation, principles of inertial accelerometers, and gyroscopes. Derivation of gimbaled and strapdown navigation equations and corresponding error analysis. Navigation using external navigation aids (navaids): LORAN, TACAN, and GPS. Introduction to Kalman filtering as a means of integrating data from navaids and inertial sensors.

AE2440 Introduction to Digital Computation
This course offers an introduction to computer system operations and program development using NPS computer facilities. The main goal of the course is to provide an overview of different structured programming techniques, along with introduction to MATLAB/Simulink/GUIDE and to use modeling as a tool for scientific and engineering applications. The course discusses the accuracy of digital computations, ways to incorporate symbolic computations, and presents numerical methods in MATLAB functions.

CS4330 Introduction to Computer Vision
This course introduces students to the main concepts that allow computers to "see" and understand visual information. It teaches methods and skills in image processing, pattern recognition, statistical analysis, classification, and learning. These are exemplified on applications such as military intelligence, surveillance, object tracking, robotic navigation, human-computer interfaces, and visual effects. Students complete a small class project that demonstrates the use of computer vision for an application of their interest. In laboratory activities, students get hands-on experience with the most important tools for building practical vision systems.

EC4310 Fundamentals of Robotics
This course presents the fundamentals of land-based robotic systems covering the areas of locomotion, manipulation, grasping, sensory perception, and teleoperation. Main topics include kinematics, dynamics, manipulability, motion/force control, real-time programming, controller architecture, motion planning, navigation, and sensor integration. Several Nomad mobile robots will be used for class projects. Military applications of robotic systems will be discussed.

AE4860 Space Control

This course covers the fundamentals of Space Control, one of the five space mission areas identified in Joint Publication 3-14. Provides in depth understanding of the history, policies, doctrine, organizations, technical systems, techniques and operations for Space Situational Awareness, Offensive Space Control, and Defensive Space Control. Students will conduct small team research projects.

ME2801 Introduction to Control Systems

This course presents classical analysis of feedback control systems using basic principles in the frequency domain (Bode plots) and in the s-domain (root locus). Performance criteria in the time domain such as steady-state accuracy, transient response specifications, and in the frequency domain such as bandwidth and disturbance rejection are introduced. Simple design applications using root locus and Bode plot techniques will be addressed in the course. Laboratory experiments are designed to expose the students to testing and evaluating mathematical models of physical systems, using computer simulations and hardware implementations.ME2801 and EC2300 are equivalent courses. This course can be offered as an online course.

ME3801 Dynamics and Control of Marine and Autonomous Vehicles I

First part of the course develops 6DOF equations of motion of marine and autonomous vehicles. Initially we discuss kinematics, followed by vehicle dynamics and overview of forces and moments acting on the marine/autonomous vehicles. Second part of the course introduces basic concepts of linear systems analysis as well as linear systems design using state-space techniques. All the examples used in the second part of the course are based on the model of an Autonomous Underwater Vehicle derived in the first part. The course includes a lab that further illustrates the concepts developed in class using hardware-in-the loop simulation of an autonomous vehicle.

ME4703 Missile Flight and Control

Tactical Missile Flight Dynamics, Guidance and Control. Kinematics and dynamics of motion, forces and moments acting on the missile, coordinate frames and transformations, concepts of stability and control. Key principles of feedback control. Stability and performance specifications, Concept of controllability, PID control. Lateral autopilot design, classical and modern design approaches; agility in maneuvering trajectories. Homing loop design, operational requirements. Principles of missile guidance as a control task; stability of guidance laws. Pursuit guidance equation, constraints, and the associated performance specifications; firing envelope, "no-escape envelope." Proportional navigation guidance law, stability and performance specifications of PN guidance. Metrics of objective comparison of guidance laws and their applicability in specific scenarios of engagement. Additional topics are selected from the following areas to address the general interests of the class: advanced guidance laws, passive sensors, INS guidance, fire control and tracking systems.

Specialisation Track: Cyber Security and Defence (CSD)

CS3101 Theory of Formal Languages and Automata
his course will cover the Chomsky hierarchy of Formal Languages (regular sets, context-free languages, context-sensitive languages, and recursively enumerable languages) and the types of grammars and automata associated with each class in the hierarchy. Emphasis is placed on the major results of the theory as they apply to language and compiler design. In addition, the major results involving the concept of in decidability are covered.

CS3670 Secure Management of Systems
This course provides students with a security manager's view of the diverse management concerns associated with administering and operating an automated information system facility with minimized risk. Students will learn how to operate a computer facility securely, legally and efficiently, with emphasis on DOD policies. This course is one of a set of courses that can earn a student the Cyber Security Fundamentals academic certificate.

CS3690 Network Security
This course covers the concepts and technologies used to achieve confidentiality, integrity, and authenticity for information processed across networks. Topics include: fundamentals of TCP/IP-based networking, core network security principles, traffic filtering types and methodology, packet-level traffic analysis, employment of cryptography, tunneling/encapsulation, Public Key Infrastructure (PKI), remote authentication protocols, and virtual private networks based on the IPSec, L2TP, and SSL protocols.

CS4558 Network Traffic Analysis
Explores fundamentals of packet-switched network traffic analysis at the network layer and above as applied to problems in traffic engineering, economics, security, etc. Explores the design and integration of analytic tools and techniques into the fabric of the network including: spatial and temporal anomaly detection, origin-destination matrix estimation, application mix determination, deep-packet inspection, fingerprinting, intrusion detection and insider threat mitigation. Finally, the course covers active defense and offensive methods reliant on traffic analysis.

CS4600 Secure System Principles
An advanced course that focuses on key principles of a constructive approach to secure systems. A brief review of operating systems and computer architecture is provided. Major topics include threat characterization and subversion; confinement; fundamental abstractions, principles, and mechanisms, such as reduced complexity, hierarchical relationships, least privilege, hardware protection, resource management and virtualization, software security, secure system composition, mutual suspicion, synchronization, covert and side-channel analysis, secure metadata, secure operational states, usability, and life cycle assurance. Current developments will include advances in security hardware, components, and systems.

CS4684 Cyber Security Incident Response and Recovery
This course defines the nature and scope of cyber security incident handling services, including intrusion/incident detection, damage control, service continuity, forensic analysis, service/data restoration, and incident reporting. Material covers policy, planning, operations, and technology issues involved in related cyber incident handling plans; i.e., Business Continuity, Disaster Recovery, and Continuity of Operations. Specific incident types addressed include, natural disasters, denial of service, malicious code, malicious misuse of hardware and firmware, unauthorized access, data compromise and inappropriate use, including insider attacks. Emphasis is given to the detection and analysis of infiltration and exfiltration techniques employed during cyber attacks, thus enabling the incident handler to detect low noise attacks, and to deconstruct particularly insidious attacks. Based upon the choice of case studies, this course will be taught at either the unclassified or TS/SCI levels.

CY4700 Applied Defensive Cyberspace Operations

This course explores methods for discovering adversarial presence in a network and defending against adversarial TTPs (tactics, techniques, and procedures). Topics include, but are not limited to the cyber kill chain, techniques the adversary uses to remain hidden within a compromised network, adversarial command and control, malware triage, mitigation of malware, and eviction of an adversary from an operational network. Lab assignments will reinforce material taught in class.

CS4650 Fundamentals of Information Systems Security Engineering

This course presents the fundamental principles and processes of information systems security engineering (ISSE). The ISSE life cycle model consists of five stages: requirements definition, design, implementation, testing and deployment. The processes involved in these stages are explained in the context of a Defense-in-Depth protection strategy, with an emphasis on the role of security requirements engineering (SRE) in the construction of a secure system. This course covers the concepts and techniques needed to systematically elicit, derive and validate security requirements. It introduces how these techniques can be used in practice, and addresses the relationship between SRE and secure system design. Course work will be a combination of lectures, case studies and a team-based SRE project.

MV2921 Introduction to MOVES

This course is designed to support introductory subject matter of special interest and is dependent on faculty availability. Topics will typically augment those offered in the basic core courses. This course may be lecture- or lab-oriented, or self-paced, with prerequisites determined by the instructor. Students may repeat this course for credit with a different topic.

MV3202 Computer Graphics Programming

An introduction to the principles of the hardware and the software used in the production of computer generated images. The objective of the course is to instruct students in 3D graphics programming. Topics include graphics programming in a window environment, basic rendering and colour, transformations, font rendering, selection, lighting and hidden surface elimination. The primary focus of the course is the design and implementation of a major project involving 3D graphics. The course is intended for students who are proficient in the development of software systems.

MV3203 Graphical Simulation

Teaches the theory and techniques relevant to rapid construction of small to medium sized graphical simulations using existing simulation platforms, such as Delta3D, VBS2, Unreal, etcetera, including web browsers with plug-ins for Flash or X3D: For use as a stimulus for human performance experiments, as partial task trainers; as visualizations to support analysis; as test beds for new hardware or software technology.

MV3500 Internetwork Communications and Simulation

An introduction to network communications in simulation applications. Topics include an introduction to the TCP/IP protocol stack; TCP/IP socket communications, including TCP, UDP, and multicast; and protocol design issues, with emphasis on Distributed Interactive Simulation and High Level Architecture. The emphasis will be on Windows and Web-browser applications.

MV3922 Introduction to Virtual Environment Technology

This course is an introduction to the technology used in virtual environments and discusses applications that use virtual environments. It is intended to give the students an introduction to the items they are likely to use throughout the master's degree program in Modeling, Virtual Environments, and Simulation (MOVES).

MV3923 Introduction to Research in MOVES

This course will examine the current and planned research of Modeling, Virtual Environments, and Simulation (MOVES) faculty in multiple fields of study. The course is designed to support MOVES students in the selection of emphasis blocks and an area for thesis research. Includes readings and exercises.

MV4001 Human Factors of Virtual Environments

This course focuses on human factors issues in virtual environments (VEs). While the similarities of VEs to the real world can often make VE interfaces intuitive and easy to use, the differences between VEs and the real world can often be the cause of serious performance problems and physical inability to effectively use a system. The design of effective VE systems depends on an understanding of humans and their interaction with their environment. Only then can a VE system hope to achieve reasonable performance levels and acceptability. This course will survey the VE literature on issues of human performance, perception, cognition, multimodal interfaces, locomotion, wayfinding, object selection and manipulation, visualization, simulator sickness, and performance differences between individuals.

MV4460 Management of Modelling and Simulation Development

The purpose of this course is to prepare MOVES students to manage large-scale modelling and simulation projects. The course traces the development life cycle of modelling and simulation systems, including, but not limited to, project management, measurement, life cycle models, requirements, implementation, testing, verification, and deployment of large-scale systems typical of DoD acquisition.

MV4002 Simulation and Training

This course focuses on training issues in virtual environments (VEs). VEs have often been considered to be general purpose trainers. However, systems are often built without an understanding of how to build a trainer that can verify that it improves subsequent performance without forming bad habits or other reverse training artefacts. This course will first investigate VE training systems from a theoretical perspective, focusing on learning, memory, and cognition. From this framework, actual training systems will be studied with the focus being on an actual study of training transfer of a real training system. Students will be required to participate in a training transfer study and to formally present their results in written form.

MV4503 Simulation Interoperability Practicum

This course provides students with hands-on experience with the issues around connecting live, virtual, and constructive simulations into a single federation. Students will deepen their understanding of High Level Architecture down to the Federation Object Model and Simulation Object Model level. They will encounter data and timing incompatibility issues, and learn the tools and techniques currently used to resolve them. They will develop a practical understanding of information assurance requirements on simulations and how they can be addressed.

MV4924 Current Topics in MOVES

The course is designed to provide breadth in MOVES not normally provided by other classroom material, as well as focus in major areas of MOVES. Faculty and research staff attend class sessions, providing the opportunity to interact with a broad group once a week, and with a focused group of the student's choosing once a week. Course is expected to be repeated and is required of all MOVES students every quarter starting with their fourth quarter in the curriculum. It includes student presentations and readings.

CS3310 Artificial Intelligence

Survey of topics and methods of Artificial Intelligence. Methods include rule-based systems, heuristic search and exploitation of natural constraints, means-ends analysis, semantic networks, and frames. Emphasis is placed on solving problems that seem to require intelligence rather than attempting to simulate or study natural intelligence. Projects to illustrate basic concepts are assigned.

List of Electives

MV4025 Cognitive and Behavioral Modeling for Simulations

This course focuses on the primary technologies used to model cognition and behavior in order to create agents that represent human beings in simulations. Topics include the dominant technologies in use, the tools used to support them, and their application to the various capabilities required of an agent. The modeling technologies covered include the production-system approaches common in artificial intelligence/cognitive science/psychology, as well as the finite-state, automata-inspired approaches that are part of engineering practice in computer-generated force simulations and the computer entertainment industry. The full scope of the modeling problem will be addressed, from sensation and perception through situation awareness and action selection, to action execution. Approaches to modeling communication and behavior moderators (e.g., experience, emotion, fatigue) will also be discussed.

MV4657 Modeling and Simulation for Stability, Security, Transition, and Reconstruction (SSTR) Operations

The purpose of this course is to explore the challenges of modeling non-traditional combat for today's war fighters. This course investigates issues, challenges, and opportunities for application of modeling and simulation (M&S) to military support for Stability, Security, Transition, and Reconstruction (SSTR) operations. The course considers application of M&S for SSTR from the perspectives of analysis, training, acquisition, and mission planning/rehearsal. Students are given hands-on experience with current and emerging SSTR M&S simulations and computational tools. Meet prerequisites or consent of the instructor.

OS3311 Probability Models for Military Applications

An intermediate course in probability modeling focused on military systems and combat situations. Following a review of random variables, probability distributions, expected values and variance, we will present a selection of probability models that range from elementary models that describe static and simple dynamic military (mostly combat) related situations, to Markov models that represent more complex combat situations (e.g., tactical battle) and processes (e.g., surveillance and employment of UAVs).

Specialisation Track: Operations Research, Modelling & Simulation

OA3103 Data Analysis
Techniques for analyzing summarizing and comparing sets of real data with several variables. Computations are done in a statistical package and a common spreadsheet program. Mode building and verification, graphical methods of exploration. Least squares regression, logistic and Poisson regression, introduction to categorical data analysis, principal components and/or classification.

OA3201 Linear Programming
Theory of optimization of linear functions subject to linear constraints. The simplex algorithm, duality, sensitivity analyses, parametric linear programming. Applications to resource allocation, manpower planning, transportation and communications, network models, ship scheduling, etc. Introduction to computer-based linear programming systems.

OA3301 Stochastic Models I
Course objectives are to provide an introduction to stochastic modelling. Topics include the homogeneous Poisson process and its generalisation and discrete and continuous time Markov chains and their applications in modelling random phenomena in civilian and military problems.

OA3302 Simulation Modelling
Discrete event digital simulation methodology. Monte Carlo techniques, use of simulation languages. Variance reduction techniques, design of simulation experiments and analysis of results.

OA3900 Workshop in Operations Research
(Variable hours 2-0 to 5-0.) This course may be repeated for credit if course content changes. Graded on Pass/Fail basis only.

OA4106 Advanced Data Analysis
The course features the blending of sophisticated statistical software and data from recent DoD applications. The manipulation of multivariate data and statistical graphics are emphasized. Methodologies presented can include survival analysis, classification and discrimination, categorical data analysis, and sample survey methods.

OA4301 Stochastic Models II
Course objectives are to discuss methods of stochastic modeling beyond those presented in OA3301 and give students the opportunity to apply the methods. Topics include conditioning; renewal processes; renewal reward processes; length-biased sampling, semi-Markov models, and novel queuing, reliability and maintenance models. The topics are illustrated by DoD applications. This course also is offered as MA4305.

OA4333 Simulation Analysis
Advanced techniques of model development and simulation experimentation. Discussion of current research. Actual topics selected will depend on the interests of the students and instructor.

OA4201 Nonlinear Programming
Convex Sets, convex functions, and conditions for local and global optimality. Elements and convergence of algorithms for solving constrained and unconstrained optimization problems. Introduction to algebraic modelling languages. Many applications of integer and non linear programming to military and civilian problems, such as weapons assignments, force structuring, parameter estimation for nonlinear or constrained regression, personnel assignment and resource allocation.

OA4202 Network Flows and Graphs

Introduction to formulation and solution of problems involving networks, such as maximum flow, shortest route, minimum cost flows, and PERT/CPM. Elements of graph theory, data structure, algorithms, and computational complexity. Applications to production and inventory, routing, scheduling, network interdiction, and personnel management.

OA4603 Test Evaluation

This course is designed to cover Developmental and Operational Test and Evaluation and Military Experimentation, including statistical concepts and methods frequently used in weapon system testing and experimentation environments. The course is taught from the perspective of the Program Manager, Test Project Officer, Test Engineer, Test Analyst, and Statistician. A number of actual military cases are used for examples. Topics include the Role of Test and Evaluation in Systems Engineering and Acquisition Management, Test Planning and Design, Development of Measures of Effectiveness and Measures of Performance, Conduct of Tests, Data Analysis, and Reporting of Test Results. A detailed group test planning project and design exercise are included. Upon successful completion of this course, students receive DAWIA Level II and Level III Intermediate and Advanced Test and Evaluation certification.

OA4702 Cost Estimation

Advanced study in the methods and practice of systems analysis with emphasis on cost analysis; cost models and methods for program structures and single projects; relationship of effectiveness models and measures to cost analysis; public capital budgeting of interrelated projects; detailed examples of current practices.

OA4602 Joint Campaign Analysis

The development, use and state-of-the-art of campaign analysis in actual procurement and operations planning. Emphasis is on formulating the problem, choosing assumptions, structuring the analysis and measuring effectiveness. Interpreting and communicating results in speech and writing is an important part of the module. In the last three weeks, the students conduct a broad gauge, quick reaction campaign analysis as team members.

Specialisation Track: Free Electron Lasers

PC3200 Physics of Electromagnetic Sensors and Photonic Devices
An introductory survey of the physics of active and passive electromagnetic detection systems, primarily for Combat Systems students who do not elect to follow the Electromagnetic Sensors specialisation track. Basic radiometry. Introduction to radar: ranging, pulse rate and range ambiguity, Doppler measurements, radar equation, target cross-sections, antenna beam patterns and phased arrays. Optoelectronic displays: CRTs, LEDs, LCDs, plasma displays. Introduction to lasers: transitions, population inversion, gain, resonators, longitudinal and transverse resonator modes, Q-switching, mode-locking, laser applications. Photodetection basics: noise and its characterization, photovoltaic, photoconductive and photoemissive detectors, image intensifiers, CCDs, night vision systems. Introduction to optical fibers and their applications.

PH2652 Modern Physics
An introduction to modern physics. Theory of relativity; blackbody radiation; photoelectric effect; matter waves; atomic spectral lines; Bohr model of the atom; uncertainty relations (position-momentum and time-energy); the Schrödinger equation (time dependent and independent); probability interpretation; infinite, finite and parabolic potential wells; tunneling (single and double barriers); electron spin and exclusion principle; the periodic table; molecular energy levels; quantum statistics (Bose-Einstein, Fermi-Dirac).

PH3152 Analytical Mechanics
Dynamics of systems of particles, including rockets. Hamilton's principle, Lagrangian dynamics, and the role of physical symmetry. Velocity-dependent potentials. The inertia tensor and rotational dynamics of rigid bodies. Small-amplitude oscillations of systems of particles, and normal modes.

PH3360 Electromagnetic Wave Propagation
Introduction to vector fields and the physical basis of Maxwell's equations. Wave propagation in a vacuum, in dielectrics and conductors, and in the ionosphere. Reflection and refraction at the interface between media. Guided waves. Radiation from a dipole.

PH3991 Theoretical Physics
Discussion of heat flow, electromagnetic waves, elastic waves, and quantum-mechanical waves; applications of orthogonal functions to electromagnetic multipoles, angular momentum in quantum mechanics, and to normal modes on acoustic and electromagnetic systems. Applications of complex analysis to Green Function in quantum mechanics and electromagnetism. Application of Fourier series and transforms to resonant systems. Applications of partial differential equation techniques to equation of physics. Prerequisites: Basic physics, multivariable calculus, vector analysis, Fourier series, complex numbers, and ordinary differential equations.

PH3992-3998 Special Topics in Intermediate Physics (Variable Hours 1-0 to 4-0.) (V-0) As Required
Study in one of the fields of intermediate physics and related applied areas selected to meet special needs or interests of students. The course may be conducted as a seminar or supervised reading in different topics. Prerequisites: A 2000 level course appropriate to the subject to be studied, and consent of the Department Chairman. The course may also be taken on a Pass/Fail basis, provided the student has requested so at the time of enrollment.

PH4001 Physics Thesis Presentation
This course provides students with the opportunity to develop the ability to deliver a briefing on a technical subject by presenting their thesis to other students and faculty. This course is required of all students working for a degree from the Physics Department and of all Combat Systems students not presenting their thesis in some other department. Prerequisites: At least two quarters of thesis research.

PH4656 Quantum Mechanics

Free particles and wave packets, the uncertainty principle, Schrodinger equation, eigenstates and eigen functions, stationary and scattering states, identical particles and the exclusion principle, atomic energy levels, quantum theory of angular momentum, hydrogen atom, coupling of angular momentum with spin, the periodic table, nuclear structure and radioactivity; fission and fusion, time independent perturbation theory, time dependent perturbation theory; selection rules for dipole radiation, magnetic effects (MRI, GMR etc.), quantum computing.

PH4858 Weapon Lethality and Survivability

This course teaches the physics and engineering concepts underlying two specific weapon systems currently in development for future US Navy electric ships: directed energy free electron/solid state lasers and the electromagnetic railgun. The directed energy topics include current program reviews, laser target damage, laser beam propagation through the atmosphere, thermal blooming, and the physics of free electron and solid state lasers. For the railgun, topics include electromagnetic gun theory and critical design issues including power conditioning, barrel design, barrel life, projectile design, and system cooling.

PH4911 Simulation of Physical and Weapon Systems

The role of computation physics in modern weapons development and combat simulations is studied. The programming language is C within the UNIX, Apple, or Windows operating systems. Applications emphasize physical principles of weapons development, systems engineering, and the use of graphics. Subject matter includes random number distributions, projectile and fragment dispersion, missile defense, free electron laser simulation, laser beam propagation in a turbulent atmosphere, thermal blooming, diffraction and numerical integration methods. Optional topics include molecular dynamics in solids, liquids, and gases, wave propagation in various media, chaos, and quantum mechanical wave functions.

PH2001 Research Topics in Physics

This course will present the research expertise of the physics faculty. The course is designed to support Combat Systems Science and Technology students in their selection of their concentration and area for thesis research. The course is given in the Pass/Fail mode.

PH3360 Electro Magnetic Wave Propagation

Introduction to vector fields and the physical basis of Maxwell's equations. Wave propagation in a vacuum, in dielectrics and conductors, and in the ionosphere. Reflection and refraction at the interface between media. Guided waves. Radiation from a dipole.

PH3451 Fundamental Acoustics

Development of, and solutions to, the acoustic wave equation in fluids; propagation of plane, spherical and cylindrical waves in fluids; sound pressure level, intensity, and specific acoustic impedance; normal and oblique incidence reflection and transmission from plane boundaries; transmission through a layer; image theory and surface interference; sound absorption and dispersion for classical and relaxing fluids; acoustic behavior of sources and arrays, acoustical reciprocity, continuous line source, plane circular piston, radiation impedance, and the steered line array; transducer properties, sensitivities, and calibration. Laboratory experiments include longitudinal waves in an air-filled tube, surface interference, properties of underwater transducers, three-element array, speed of sound in water, and absorption in gases.

PH3452 Underwater Acoustics

This course is a continuation of PH3451. Lumped acoustic elements and the resonant bubble; introduction to simple transducers; normal modes in rectangular and cylindrical enclosures; steady-state response of acoustic waveguides of constant cross section, propagating evanescent modes, and group and phase speeds; transmission of sound in the ocean, the Eikonal Equation and necessary space conditions for ray theory, and refraction and ray diagrams; sound propagation in the mixed layer, the convergence zone, and the deep sound channel; passive sonar equation, ambient noise and doppler effect and bandwidth considerations; active sonar equations, target strength and reverberation. Laboratory experiments include Helmholtz resonators, normal modes in rectangular, cylindrical, and spherical enclosures, water-filled waveguide, noise analysis, impedance of a loudspeaker.

PH4272 Lasers Optoelectronics and Electro-Optics II

The second course in a two-course sequence covering the physics of lasers, optoelectronic and electro-optical devices. Physics of optoelectronic detection, noise, detector figures-of-merit. Photovoltaic, photoconductive, bolometric and charge-coupled (CCD) detector families. 1-D and 2-D (focal-pave array) detectors. Image intensifiers and night vision systems. Gaussian beams. Physics of optical fibers and their practical applications. Optical properties of anisotropic media and their applications, electro-optical effects and modulators. Introduction to nonlinear optics, optical harmonic generation, parametric amplification and optical heterodyning.

PH4857 Physics of High Velocity Impact, Weapon Lethality, and Survivability

This course is the first of a two course sequence on the physics and systems engineering concepts underlying weapon systems and weapon systems integration. Topics include: basics of stress-strain relations in various materials; elastic-plastic waves and shocks in solid materials; explosively driven fragments and materials; physics of fragment and rod-like penetration into solid targets; kill mechanisms; vulnerability, survivability and kill probability considerations; and basics of warhead design.

PH4858 Electric Ship Weapons Systems

This is the second of a two course sequence on the physics and systems engineering concepts underlying weapon systems and weapon systems integration. Topics include: the basic laser range equation and estimate of kill requirements; candidate laser systems for weapons applications; laser propagation effects from absorption, turbulence and blooming; laser target interaction by melting and by impulse; high power microwave principles and applications; and railgun theory and critical issues-power conditioning, barrel design and life, projectile design, cooling.

PH3991 Theoretical Physics

Discussion of heat flow, electromagnetic waves, elastic waves, and quantum-mechanical waves; applications of orthogonal functions to electromagnetic multipoles, angular momentum in quantum mechanics, and to normal modes on acoustic and electromagnetic systems. Applications of complex analysis to Green Function in quantum mechanics and electromagnetism. Application of Fourier series and transforms to resonant systems. Applications of partial differential equation techniques to equation of physics. Prerequisites: Basic physics, multivariable calculus, vector analysis, Fourier series, complex numbers, and ordinary differential equations.

PH4271 Lasers Optoelectronics and Electro-Optics I

The first course in a comprehensive two-course sequence covering the physics of lasers, optoelectronic and electro-optical devices. Review of Atomic and molecular energy levels, time-dependent perturbation theory, radiative transitions, transition rates. Einstein A and B coefficients for spontaneous and stimulated radiative transitions, blackbody radiation. Optical attenuation and amplification, rate equations. Basic laser theory, gain saturation, homogeneous and inhomogeneous effects. Optical resonators, laser modes, coherence. Q-switching, mode locking, pulse compression, laser pumping and tuning mechanisms. Gaussian beams. Introduction to multiple-mode and single mode optical fibers.

PH3280 Introduction to MEMS Design

This is a 4.5 credit hour class introducing the students to Micro Electro Mechanical Systems (MEMS). Topics include material considerations for MEMS and microfabrication fundamentals. Surface, bulk and non-silicon micromachining. Forces and transduction; forces in micro-nano-domains and actuation techniques. Case studies of MEMS based microsensor, microactuator and microfluidic devices. The laboratory work includes computer aided design (CAD) of MEMS devices and small group design project. Prerequisites: basic understanding of electrical and mechanical structures.

PH4454 Sonar Transducer Theory and Design

A treatment of the fundamental phenomena basic to the design of sonar transducers, specific examples of their application and design exercises. Topics include piezoelectric, magnetostrictive and hydro mechanical effects. Laboratory includes experiments on measurement techniques, properties of transducer materials, characteristics of typical navy transducers, and a design project. A field trip to visit one or more transducer manufacturers is normally scheduled during the course.

PH3052 Physics of Space and Airborne Sensor Systems

This interdisciplinary course explores the physical principles underlying the sensor systems needed for satellites and tactical aircraft, as well as limitations imposed by the atmosphere and operating environment on these systems and their communication links. Topics include: satellite orbits, the satellite environment, ionospheric interactions and atmospheric propagation, phased array and pulsed compressed radars, imaging synthetic aperture and inverse synthetic aperture radars, noise resources, thermal radiation, principles of semiconductor devices, optical and infrared imaging detector systems, and their resolution limitations and bandwidth requirements. Prerequisites: Basic physics class. Must be familiar with the concepts of energy and wave motion.

EC4450 Sonar Systems Engineering

Mathematical development and discussion of fundamental principles that pertain to the design and operation of passive and active sonar systems critical to naval operations. Topics from complex aperture theory, array theory, and signal processing are covered. This course supports the undersea warfare and engineering acoustics curricula and others.

PH3292 Applied Optics

An intermediate-level course in optics. Review of basic geometric and physical optics concepts. Laws of reflection and refraction at interfaces. Imaging systems and aberrations. Polarization; Jones matrix methods; electro-optical modulation. Matrix methods for paraxial ray tracing and optical systems analysis. Two-beam and multiple-beam interference; Young's double slit experiment, multiple-slit systems and diffraction gratings; Michelson's interferometer; Fabry-Perot interferometer. Huygens-Fresnel principle; Fraunhofer diffraction; Fresnel diffraction.

PH3655 Solid State Physics

Formation of solids, crystal structure of semiconductors, X-ray diffraction, lattice vibrations, defects, electrical and thermal properties, free electron model, Seebeck effect, thermionic emission, photoemission, effects of periodic potential, formation of energy bands, E-k relation, band structure of Si and GaAs, electrons and holes, doping and impurity levels, mobility, diffusion, continuity equation, Schottky and ohmic contacts, optical properties, Formation of p-n junction, I-V characteristics, bipolar and field effect transistors, fabrication technology, semiconductor alloys, quantum effect devices, fundamental limits to semiconductor device technology.

PC4860 Advance Weapons Concepts

This course is a comprehensive overview of the components and underlying technologies of modern missile technologies. The course gives an introduction to missile guidance, missile aerodynamic design considerations, and missile propulsion technologies, followed by an introduction to the physics of modern conventional warhead designs for missile intercept and lethality and survivability considerations.

PH4455 Sound Propagation in the Ocean

An advanced treatment of the subject. Topics include: reflection of spherical waves from ocean boundaries; normal mode propagation of sound; inhomogeneous wave equation and the point source in cylindrical coordinates; shallow water channel with fluid and solid bottoms; the deep sound channel and the WKB approximation; range-dependent channels; adiabatic normal modes and the parabolic equation; multi-path propagation; application to matched field processing and source localization.

Specialisation Track: Operational Oceanography

OC0999 Thesis Seminars
Students in the various oceanography curricula present their thesis research. Prerequisites: Preparation of a thesis.

OC3140 Probability and Statistics for Air-Ocean
Basic probability and statistics, in the air-ocean science context. Techniques of statistical data analysis. Structure of a probability model, density distribution function, expectation, and variance. Binomial, Poisson and Gaussian distributions. Conditional probability and independence. Joint distributions, covariance and central limit theorem. Transformations of random variables. Histograms and empirical distributions and associated characteristics such as moments and percentiles. Standard tests of hypotheses and confidence intervals for both one-and two-parameter situations. Regression analysis as related to least squares estimation.

OC3150 Analysis of Air Ocean Time Series
Analysis methods for atmospheric and oceanic time series. Fourier transforms applied to linear systems and discrete data. Correlation functions, power density spectra and cross-spectrum. Optimal design of air-ocean data network. Laboratory work involves analysis of actual atmospheric and ocean time series using principles developed in class. Prerequisites: A probability and statistics course.

OC3230 Descriptive Physical Oceanography
Physical properties of seawater. Processes influencing the distribution of heat, salt and density in the ocean. Static stability in the ocean. Circulation and water masses in the ocean. Laboratory work involves collection and analysis of actual data using principles developed in class.

OC3240 Ocean Circulation Analysis
Application of dynamic concepts of ocean circulation, including conservation of mass, momentum and energy. Oceanic currents without friction: inertial and geostrophic flows. Frictional currents: Reynolds equations, Ekman and wind-driven flows. Vorticity balance: Sverdrup transport, potential vorticity, topographic steering, western intensification and Rossby waves. Thermohaline effects and thermocline theory.

OC3260 Fundamentals of Ocean Acoustics
The fundamentals of ocean acoustics, including the acoustic wave equation, ray theory, acoustic arrays and filters, ambient noise, scattering, absorption, an introduction to normal mode theory, and sonar equations. Laboratory emphasizes acoustic signal processing techniques.

OC3321 Air-Ocean Fluid Dynamics
A foundation course for studies of atmospheric and oceanographic motions. The governing dynamical equations for rotating stratified fluid are derived from fundamental physical laws. Topics include the continuum hypothesis, real and apparent forces, derivations and applications of the governing equations, coordinate systems, scale analysis, simple balanced flows, boundary conditions, thermal wind, barotropic and baroclinic conditions, circulation, vorticity, and divergence. Prerequisites: Multi-variable calculus, vectors, and ordinary differential equations (may be taken concurrently).

OC4271 Topics in Tactical Oceanography
Course emphasizes the tactical use of the environment and battlespace characterization as a force multiplier in naval operations, including acoustic undersea warfare, special operations, amphibious warfare, and mine warfare. Using tailored lectures, students will examine oceanographic conditions and the ability for naval forces to exploit them in nearshore, coastal and deep ocean settings.

OC4211 Ocean Dynamics II

Linear theory of surface, internal, inertial-internal and Rossby waves, barotropic and baroclinic instabilities. Coastal and equatorial trapped waves.

OC4210 Littoral Field Studies

Employs the scientific method for studying nearshore and wave processes using field observations in littoral battlespace environments. Monterey Bay, CA will be used as a natural laboratory for studying a plethora of littoral related topics. Students will design a small nearshore field experiment or set of experiments, deploy state-of-the-art instrumentation, and analyze data to test relevant nearshore hypotheses. Students will write a mini-proposal with budget focused on their scientific hypothesis, experiment, and analysis, and write a scientific final report. Introductions and limitations of instrumentation will be discussed and integrated into the field design, which will include deployment schemes and subsequent analyses. Data quality control and analysis techniques will be described and implemented. In particular, tidal harmonic analysis will be introduced and performed. The course is divided into 1) in-class discussions (instrumentation, deployment schemes, and data analysis techniques), and 2) field exercises that require student participation in performing the proposed small experiments. There is a high probability that students will get wet, but it is not a requirement.

OC4413 Air/Sea Interaction

Fundamental concepts in turbulence. The atmospheric planetary boundary layer, including surface layer, and bulk formulae for estimating air-sea fluxes. The oceanic planetary boundary layer including the dynamics of the well-mixed surface layer. Recent papers on large-scale air-sea interaction.

OC4900 Directed Study in Oceanography

Independent study of advanced topics in oceanography. Prerequisites: Consent of instructor and the Department Chairman. Graded on Pass/Fail basis only.

PH3991 Theoretical Physics
Discussion of heat flow, electromagnetic waves, elastic waves, and quantum-mechanical waves; applications of orthogonal functions to electromagnetic multipoles, angular momentum in quantum mechanics, and to normal modes on acoustic and electromagnetic systems. Applications of complex analysis to Green Function in quantum mechanics and electromagnetism. Application of Fourier series and transforms to resonant systems. Applications of partial differential equation techniques to equation of physics. Prerequisites: Basic physics, multivariable calculus, vector analysis, Fourier series, complex numbers, and ordinary differential equations.

PH3451 Fundamental Acoustics
Development of, and solutions to, the acoustic wave equation in fluids; propagation of plane, spherical and cylindrical waves in fluids; sound pressure level, intensity, and specific acoustic impedance; normal and oblique incidence reflection and transmission from plane boundaries; transmission through a layer; image theory and surface interference; sound absorption and dispersion for classical and relaxing fluids; acoustic behavior of sources and arrays, acoustical reciprocity, continuous line source, plane circular piston, radiation impedance, and the steered line array; transducer properties, sensitivities, and calibration. Laboratory experiments include longitudinal waves in an air-filled tube, surface interference, properties of underwater transducers, three-element array, speed of sound in water, and absorption in gases.

PH3452 Underwater Acoustics
This course is a continuation of PH3451. Lumped acoustic elements and the resonant bubble; introduction to simple transducers; normal modes in rectangular and cylindrical enclosures; steady-state response of acoustic waveguides of constant cross section, propagating evanescent modes, and group and phase speeds; transmission of sound in the ocean, the Eikonal Equation and necessary space conditions for ray theory, and refraction and ray diagrams; sound propagation in the mixed layer, the convergence zone, and the deep sound channel; passive sonar equation, ambient noise and doppler effect and bandwidth considerations; active sonar equations, target strength and reverberation. Laboratory experiments include Helmholtz resonators, normal modes in rectangular, cylindrical, and spherical enclosures, water-filled waveguide, noise analysis, impedance of a loudspeaker.

EO3402 Signals and Noise
A course in the rudiments of modern signal processing for naval officers in non-electrical engineering curricula. Topics include signal processing in the frequency domain using the DFT and FFT, random signals, their description and processing. Applications to signal detection, demodulation, filtering, beamforming, target tracking, and other relevant naval and military operations.

EC4450 Sonar Systems Engineering
Mathematical development and discussion of fundamental principles that pertain to the design and operation of passive and active sonar systems critical to naval operations. Topics from complex aperture theory, array theory, and signal processing are covered. This course supports the undersea warfare and engineering acoustics curricula and others.

PH4454 Sonar Transducer Theory and Design
A treatment of the fundamental phenomena basic to the design of sonar transducers, specific examples of their application and design exercises. Topics include piezoelectric, magnetostrictive and hydro mechanical effects. Laboratory includes experiments on measurement techniques, properties of transducer materials, characteristics of typical navy transducers, and a design project. A field trip to visit one or more transducer manufacturers is normally scheduled during the course.

PH4455 Sound Propagation in the Ocean
An advanced treatment of the subject. Topics include: reflection of spherical waves from ocean boundaries; normal mode propagation of sound; inhomogeneous wave equation and the point source in cylindrical coordinates; shallow water channel with fluid and solid bottoms; the deep sound channel and the WKB approximation; range-dependent channels; adiabatic normal modes and the parabolic equation; multi-path propagation; application to matched field processing and source localization.

UW2001 History of USW Part I, Mine Warfare
A study of mine warfare during the 20th century. Starting with the development of mines at the end of the 19th century, the progression of the warfare area is tracked through the end of the 20th century. The lessons of this history continue to have implications for the future of naval warfare. Numerous lessons reappear from the Russo-Japanese War of 1905 on through World War I, World War II, the Korean conflict, the Vietnam War, the Cold War, Desert Shield/Desert Storm, and Operation Iraqi Freedom. Technical Innovations with significant impact on this historical period are covered as part of this course.

UW2001 History of USW Part I, Yesterday, Today, Tomorrow
A study of Submarine Warfare, Anti-Submarine Warfare, and the new concept of Sub-Sea Warfare using a thematic approach. Each of these Undersea Warfare areas will be taught using applicable themes such as sensor and weapon capabilities, command and control, organization, training, and strategy. A basic Undersea Warfare framework will provide historical perspective in each of the three Undersea Warfare areas, emphasizing the status yesterday, what it is today and why, and where we need to be tomorrow. The new area of Sub-Sea Warfare, which encompasses unmanned vehicles, sea-bed infrastructure, distributed networks, and irregular warfare, will also be introduced and discussed. Upon course conclusion, students will have an appreciation of the current status of Undersea Warfare in the Navy today, where the problems and challenges exist, and how the knowledge gained from their Undersea Warfare curriculum will help the Navy develop solutions to these problems and challenges.

Suggested Electives

OC3230 Descriptive Physical Oceanography
Physical properties of seawater. Processes influencing the distribution of heat, salt and density in the ocean. Static stability in the ocean. Circulation and water masses in the ocean. Laboratory work involves collection and analysis of actual data using principles developed in class.

PH3002 Non-Acoustic Sensor Systems
This course covers the physical principles underlying the operation of a number of operational and proposed non-acoustic sensor systems. Geomagnetism, magnetometers and gradiometers, MAD signatures, optical and IR transmission in the atmosphere and in sea water. Image Converter, FLIR and radar systems for USW. Exotic detection schemes.

EC3460 Introduction to Machine Learning for Signal Analytics
This course introduces basic concepts and tools needed to detect, analyze, model, and extract useful information from digital signals by finding patterns in data. It covers some of the fundamentals of machine learning as they apply in signal and information processing. The emphasis in the course is on practical engineering applications rather than theoretical derivations to give participants a broad understanding of the issues involved in the learning process. Supervised learning tools such as the Bayes estimator, neural networks and radial basis functions, support vector machines and kernel methods are presented. Unsupervised learning tools such as k-means and hierarchical clustering are discussed. Data transformation and dimensionality reduction are introduced. Performance measures designed to evaluate learning algorithms are introduced. Concepts presented are illustrated throughout the course via several application projects of specific interest to defense related communities. Application topics may include target/signal identification, channel equalization, speech/speaker recognition, image classification, blind source separation, power load forecasting, and others of current interest.

ME3720 Introduction to Unmanned Systems

This course provides an overview of unmanned systems technology and operations, including navigation, vehicle dynamics, power and propulsion, communications, navigation, motion planning fundamentals. Operational and design considerations for single and multi-vehicle operations are presented. Volume and weight limitations on payload and range are covered as are energy and power constraints.

OA3602 Search Theory and Detection

Search and detection as stochastic processes. Characterization of detection devices, use and interpretation of sweep widths and lateral range curves, true range curves. Measures of effectiveness of search-detection systems. Allocation of search efforts, sequential search. Introduction to the statistical theory of signal detection. Models of surveillance fields, barriers, tracking and trailing.

Specialisation Track: Applied Mathematics

MA3025 Logic and Discrete Math
Provides a rigorous foundation in logic and elementary discrete mathematics to students of mathematics and computer science. Topics from logic include modeling English propositions, propositional calculus, quantification, and elementary predicate calculus. Additional mathematical topics include elements of set theory, mathematical induction, relations and functions, and elements of number theory.

MA3042 Linear Algebra
Finite-dimensional vector spaces, linear dependence, basis and dimension, change of basis. Linear transformations and similarity. Scalar product, inner product spaces. Orthogonal subspaces and least squares. LU (with pivoting), Cholesky, and QR factorizations. Eigenvalues/eigenvectors, diagonalization. Hermitian matrices, quadratic forms, definite matrices. Vector and matrix norms, orthogonal transformations, condition numbers.

MA4027 Graph Theory
Advanced topics in the theory of graphs and digraphs. Topics include graph coloring, Eulerian and Hamiltonian graphs, perfect graphs, matching and covering, tournaments, and networks. Application areas with DoD/DoN relevance range from mathematics to computer science and operations research, including applications to coding theory, searching and sorting, resource allocation, and network design

MA3560 Modern Applied Alebra
This course is devoted to aspects of modern algebra and number theory that directly support applications, principally in communication. The algebraic emphasis is on ring and field theory, with special emphasis on the theory of finite fields, as well as those aspects of group theory that are important in the development of coding theory. Elements of number theory include congruences and factorization. Applications are drawn from topics of interest to DoN/DoD. These include error correcting codes and cryptography.

MA4570 Cryptography
The methods of secret communication are addressed. Simple cryptosystems are described and classical techniques of substitution and transposition are considered. The public-key cryptosystems, RSA, Discrete Logarithm and other schemes are introduced. Applications of cryptography and cryptanalysis.

MA3607 Real Analysis
The objective of this course is for students to achieve a solid understanding of the basic concepts, analysis, and proofs in advanced calculus, including: limits, sequences, series, continuous functions, uniform convergence and uniform continuity, differentiation, and Riemann integration. This is a mathematics course in the pure sense. Proofs will be emphasized, and the student will learn how to reproduce, understand, create and enjoy mathematical proofs.

MA4560 Coding Theory
Mathematical analysis of the codes used over communication channels is made. Techniques developed for efficient, reliable and secure communication are stressed. Effects of noise on information transmission are analyzed and techniques to combat their effects are developed. Linear codes, finite fields, single and multiple error-correcting codes are discussed. Codes have numerous applications for communication in the military, and these will be addressed.

Suggested Elective modules for Certificate in Network Science

MA3046 Matrix Analysis

This course provides students in the engineering and physical sciences curricula with an applications-oriented coverage of major topics of matrix and linear algebra. Matrix factorizations (LU, QR, Cholesky), the Singular Value Decomposition, eigenvalues and eigenvectors, the Schur form, subspace computations, structured matrices. Understanding of practical computational issues such as stability, conditioning, complexity, and the development of practical algorithms.

MA4400 Game Theory

The course will develop game theoretic concepts in evaluations of the importance of players in bargaining situations and of elements in networks. Topics covered include cooperative and noncooperative games, bargaining, the Shapley Value, and coalitions. The course will study applications to military problems and applications to economics, political science, and biology. There will be extensive reading from the literature. Prerequisites: MA3042, OA3201, and an introductory course in probability.

MA4550 Boolean Functions

The course will discuss the Fourier analysis of Boolean functions and the relevant combinatorics with an eye toward cryptography and coding theory. Particular topics will include avalanche features of Boolean functions, correlation immunity and resiliency, bentness, trade-offs among cryptographic criteria and real-life applications in the designs of stream and block ciphers.

MA4404 Complex Networks

The course focuses on the emerging science of complex networks and their applications, through an introduction to techniques and models for understanding and predicting their behavior. The topics discussed will be building mainly on graph theory concepts, and they will address the mathematics of networks, their applications to the computer networks and social networks, and their use in research. The students will learn the fundamentals of dynamically evolving complex networks, study current research in the field, and apply their knowledge in the analysis of real network systems through a final project. DoD applications include security of critical communication infrastructure.

CS4558 Network Traffic Analysis

Explores fundamentals of packet-switched network traffic analysis at the network layer and above as applied to problems in traffic engineering, economics, security, etc. Explores the design and integration of analytic tools and techniques into the fabric of the network including: spatial and temporal anomaly detection, origin-destination matrix estimation, application mix determination, deep-packet inspection, fingerprinting, intrusion detection and insider threat ".

OA4202 Network Flows

Introduction to formulation and solution of problems involving networks, such as maximum flow, shortest route, minimum cost flows, and PERT/CPM. Elements of graph theory, data structure, algorithms, and computational complexity. Applications to production and inventory, routing, scheduling, network interdiction, and personnel management.

Suggested Elective modules for Certificate in Secure Communications

MA4026 Combination Math

Advanced techniques in enumerative combinatorics and an introduction to combinatorial structures. Topics include generating functions, recurrence relations, elements of Ramsey theory, theorems of Burnside and Polya, and balanced incomplete block designs. Application areas with DoD/DoN relevance range from mathematics to computer science and operations research, including applications in probability, game theory, network design, coding theory, and experimental design.

MA/CS/ 4/3xxx

Select 2 courses

Specialisation Track: Systems Engineering

OA4603 Test Evaluation
This course is designed to cover Developmental and Operational Test and Evaluation and Military Experimentation, including statistical concepts and methods frequently used in weapon system testing and experimentation environments. The course is taught from the perspective of the Program Manager, Test Project Officer, Test Engineer, Test Analyst, and Statistician. A number of actual military cases are used for examples. Topics include the Role of Test and Evaluation in Systems Engineering and Acquisition Management, Test Planning and Design, Development of Measures of Effectiveness and Measures of Performance, Conduct of Tests, Data Analysis, and Reporting of Test Results. A detailed group test planning project and design exercise are included. Upon successful completion of this course, students receive DAWIA Level II and Level III Intermediate and Advanced Test and Evaluation certification.

OS3180 Probability and Statistics for SE
This course introduces the systems engineering and analysis student to probability, descriptive statistics, inferential statistics, and regression. The modeling and analysis of the stochastic behavior of systems provides the context for the course. Topical coverage includes the normal, binomial, Poisson, exponential, and lognormal distributions; probabilistic measures of system performance; graphical and numerical data summaries; confidence intervals and hypothesis tests based on one or two samples; regression with one or more predictors; and single factor analysis of variance. The lab portion of the class uses spreadsheets to support the modeling and analyses. The course is delivered in block format.

SE3011 Engineering Economics and Cost Estimation
An introduction to the cost aspects of systems engineering, exploring cost from a decision-making perspective. Examines how cost is used to select alternatives and how the cost of systems can be measured. Concepts covered include economic analysis, cost behavior, cost allocation, system cost, life cycle costs, cost over time, cost estimating techniques, cost uncertainty, and cost risk.

SE3100 Fundamentals of Systems Engineering
Introduction to systems thinking and the processes and methods of systems engineering. The course covers fundamentals of systems engineering and system architecting, requirements analysis, functional analysis and allocation, preliminary system architecture, systems analysis, system design, and the basics of test and evaluation. Various perspectives, from frameworks, processes, and standards, such as the DoD Architecture Framework (DoDAF), DoD Joint Capabilities Integration and Development System (JCIDS), EIA 632, ISO 15288, IEEE 1220, IEEE 1471, and the International Council on Systems Engineering (INCOSE) models, are presented. Students analyze case studies. Students also use spreadsheet software for modeling and analyzing requirements and conceptual design alternatives. The course includes the application of fundamental systems engineering processes and methods to an integrative project, as well as development of communication skills through oral presentations and written reports.

SE3250 Capability Engineering
This course presents a systems engineering approach to determining military capabilities required to execute a mission set. It introduces simulation as a method for assessing performance of a capabilities portfolio. Topics covered include current DOD and Naval practices for capabilities engineering, design and assessment of capability portfolios, and use of commercial and custom simulations to analyze capability portfolio performance.

SE3302 Systems Suitability
This course presents the techniques of system design and assessment for operational feasibility, including reliability, maintainability, usability (including human factors and human performance), supportability, and producibility. Design methods for open architecture of hardware and software are presented. Software integration and management from a systems perspective is presented.

SI3400 Fundamentals of Engineering Project Management

This course examines modern techniques of engineering project management from a systems perspective, including project planning, organization, and control. Specific topics include discussion of the systems engineering management process, risk management, scheduling methodologies, the DoD acquisition environment, management of design activities, PERT, CPM, and project control mechanisms. Case studies are used to examine application of principles. Large-scale system management, mitigation of technical risk, integrated product and process development, quality management, contracting, and the international environment are discussed. Large scale systems management problems are examined using commercial software suites. Covers application of fundamental systems project management processes and methods to an integrative system project. Development of communication skills is accomplished through oral presentations and written reports.

SE4115 Combat Systems Integration

This course presents systems engineering techniques for integrating combat systems into a common system, including technology development, system development and integration, network integration, and system of systems integration. Lectures and projects exploring engineering design tools and analysis methods to meet specified systems requirements are used. Topics include engineering analysis of interfaces for power, data, mechanical, and other attributes; engineering change management; advanced collaboration environments; technology readiness levels; and integration risk mitigation.

SE4150 Systems Architecture and Design

The use of models, from stakeholder needs to requirements, to system functional and physical architecture, through performance specification, for the basis for architecting and designing complex technical systems. This course provides the student with the language, terminology, concepts, methods, and tools of system architecting and design, including exploring the relationship between science, art, and deductive and inductive processes. Topics covered include architecture modeling (e.g. Hatley/Hruschka/Pirbhai and Rummler-Brache Methods), architectural frameworks (including Zachman and DoDAF), object oriented modeling approaches using Unified Modeling Language (UML) and Systems Modeling Language (SysML), human and cultural aspects of architecturing and design, requirements generation and definition, and knowledge formation and distribution. Students carry out projects and assignments both individually and as teams.

AE2440 Introduction to Scientific Programming

This course offers an introduction to computer system operations and program development using NPS computer facilities. The main goal of this course is to provide an overview of different structured programming techniques, along with introduction to MATLAB/Simulink/GUIDE and to use modeling as a tool for scientific and engineering applications. The course discusses the accuracy of digital computations, ways to incorporate symbolic computations, and presents numerical methods in MATLAB functions.

Suggested Electives

SE4003 Systems Software Engineering

The course is designed to teach students the basic concepts of software engineering and methods for requirements definition, design and testing of software. Specific topics include introduction to the software life cycle, basic concepts and principles of software engineering, object-oriented methods for requirements analysis, software design and development. Special emphasis is placed on the integration of software with other components of a larger system.

SE3112 Combat Systems Engineering I – Introduction to Sensors

This is the first course of a survey of military sensor technology. It introduces the student to the nature of physical observables and propagators, the effects of the propagation medium on sensor performance, the relationship between signals and noise, and the characteristics of critical sensor functions (including detection, estimation, imaging, and tracking). It is designed to provide a framework for more detailed analysis of specific sensor systems in the follow-on course SE4112.

SE3113 Combat Systems Engineering II- Conventional Weapons

This is a survey of conventional military weapons technology. It introduces the student to both the effects that conventional weapons (artillery, bombs, and missiles) can produce as well as the technologies needed by weapons systems to create those effects. It is designed to provide familiarization of the student with critical weapons concepts that are necessary for enlightened examination of both technology development and military planning.

SE4112 Combat Systems Engineering III

This course applies systems engineering principles to the design of combat systems with emphasis on detection, tracking, and identification systems. Sensor technologies covered include radars, ESM, active and passive sonar, infrared, electro-optical, and magnetic/electric/gravity field sensors. The emphasis is on what the elements contribute to a combat system, their basic principles of operation, their performance limitations, trade-offs, and their interfaces with the rest of the combat system. This course builds on the material offered in SI3112 (Intro to Sensors).

SE4353 Risk Analysis & Management

This course covers three areas in the risk field - Qualitative Risk Analysis, Quantitative Risk Analysis, and Decision Risk Analysis. Qualitative Risk Analysis presents techniques for risk identification/evaluation, risk handling, risk monitoring and risk management. Quantitative Risk Analysis includes Probabilistic Risk Assessment (RPRA) of system performance and project cost/schedule. Decision Risk Analysis gives the students an understanding of how to apply risk and cost benefit techniques in decision making when one must deal with significant risk or uncertainty. The course will present a framework for balancing risks and benefits to applicable situations. Typically, these involve human safety, potential environmental effects, and large financial and technological uncertainties. Concepts are applied toward representative problems resulting in risk and decision models that provide insight and understanding, and consequently lead to more successful projects/programs with better system performance within cost and schedule.

OS3401 Human Factors in System Design

This course will provide an introduction to the field of Human Factors for Systems Engineering students with an emphasis on military systems. Humans are the most important element of any military system. Consequently, the design of effective systems must take into account human strengths and limitations as well as considerations of human variability. The course surveys human factors, human-centered design, and system effectiveness and safety. Topics include system design in light of human cognition and performance as they are influenced by physiological, anthropometric and environmental considerations. Emphasis is given to the responsibility of Systems Engineers to assure human performance and system effectiveness.

ME4751 Combat Survivability, Reliability and Systems Safety Engineering

This course provides the student with an understanding of the essential elements in the study of survivability, reliability and systems safety engineering for military platforms including submarines, surface ships, fixed-wing and rotary wing aircraft, as well as missiles, unmanned vehicles and satellites. Technologies for increasing survivability and methodologies for assessing the probability of survival in a hostile (non-nuclear) environment from conventional and directed energy weapons will be presented. Several in-depth studies of the survivability various vehicles will give the student practical knowledge in the design of battle-ready platforms and weapons. An introduction to reliability and system safety engineering examines system and subsystem failure in a non-hostile environment. Safety analyses (hazard analysis, fault-tree analysis, and component redundancy design), safety criteria and life cycle considerations are presented with applications to aircraft maintenance, repair and retirement strategies, along with the mathematical foundations of statistical sampling, set theory, probability modeling and probability distribution functions.

Modules on “Management and Systems Acquisition” are available as Electives. Please work with the NPS Academic Associate and Program Officer for actual courses.

Specialisation Track: Systems Engineering Analysis

SE3100 Fundamentals of Systems Engineering

Introduction to systems thinking and the processes and methods of systems engineering. The course covers fundamentals of systems engineering and system architecting, requirements analysis, functional analysis and allocation, preliminary system architecture, systems analysis, system design, and the basics of test and evaluation. Various perspectives, from frameworks, processes, and standards, such as the DoD Architecture Framework (DoDAF), DoD Joint Capabilities Integration and Development System (JCIDS), EIA 632, ISO 15288, IEEE 1220, IEEE 1471, and the International Council on Systems Engineering (INCOSE) models, are presented. Students analyze case studies. Students also use spreadsheet software for modeling and analyzing requirements and conceptual design alternatives. The course includes the application of fundamental systems engineering processes and methods to an integrative project, as well as development of communication skills through oral presentations and written reports.

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The use of models, from stakeholder needs to requirements, to system functional and physical architecture, through performance specification, for the basis for architecting and designing complex technical systems. This course provides the student with the language, terminology, concepts, methods, and tools of system architecting and design, including exploring the relationship between science, art, and deductive and inductive processes. Topics covered include architecture modeling (e.g. Hatley/Hruschka/Pirbhai and Rummler-Brache Methods), architectural frameworks (including Zachman and DoDAF), object oriented modeling approaches using Unified Modeling Language (UML) and Systems Modeling Language (SysML), human and cultural aspects of architecturing and design, requirements generation and definition, and knowledge formation and distribution. Students carry out projects and assignments both individually and as teams.

SE4115 Combat Systems Integration

This course presents systems engineering techniques for integrating combat systems into a common system, including technology development, system development and integration, network integration, and system of systems integration. Lectures and projects exploring engineering design tools and analysis methods to meet specified systems requirements are used. Topics include engineering analysis of interfaces for power, data, mechanical, and other attributes; engineering change management; advanced collaboration environments; technology readiness levels; and integration risk mitigation.

OS3680 Naval Tactical Analysis

This course surveys and applies various tools of operational and decision analysis to naval tactical problems. Topics include basic operational and tactical problem formulation, tactical decision analysis, and the application of uncertainty models for tactical problems in search and detection and weapons effectiveness.

OS3180 Probability and Statistics for Systems Engineering

This course introduces the systems engineering and analysis student to probability, descriptive statistics, inferential statistics, and regression. The modeling and analysis of the stochastic behavior of systems provides the context for the course. Topical coverage includes the normal, binomial, Poisson, exponential, and lognormal distributions; probabilistic measures of system performance; graphical and numerical data summaries; confidence intervals and hypothesis tests based on one or two samples; regression with one or more predictors; and single factor analysis of variance. The lab portion of the class uses spreadsheets to support the modeling and analyses. The course is delivered in block format.

OS3211 Systems Optimization

This course is an application-oriented introduction to optimization. It introduces models (linear, integer and nonlinear programs), modeling tools (sensitivity and post-optimality analysis), and optimization software and solution techniques (including heuristics). It presents many military and private sector optimization applications in production planning and scheduling, inventory planning, personnel scheduling, project scheduling, distribution systems planning, facility sizing and capacity expansion, communication systems design, and product development.

OS4680 Naval Systems Analysis

This course covers the techniques for the analysis of proposed and existing systems. It includes analysis of alternatives and models in decision making, optimization in design and operations, queuing theory and analysis, Markov analysis, and selected topics to support project work. Students analyze case studies and complete a course project. Students also use spreadsheet software for modeling and analyzing design alternatives, and develop communication skills by writing reports of analyses.

OS3680 Naval Tactical Analysis

This course surveys and applies various tools of operational and decision analysis to naval tactical problems. Topics include basic operational and tactical problem formulation, tactical decision analysis, and the application of uncertainty models for tactical problems in search and detection and weapons effectiveness.

SE4354/OA4603 Test Evaluation

This course is designed to cover Developmental and Operational Test and Evaluation and Military Experimentation, including statistical concepts and methods frequently used in weapon system testing and experimentation environments. The course is taught from the perspective of the Program Manager, Test Project Officer, Test Engineer, Test Analyst, and Statistician. A number of actual military cases are used for examples. Topics include the Role of Test and Evaluation in Systems Engineering and Acquisition Management, Test Planning and Design, Development of Measures of Effectiveness and Measures of Performance, Conduct of Tests, Data Analysis, and Reporting of Test Results. A detailed group test planning project and design exercise are included. Upon successful completion of this course, students receive DAWIA Level II and Level III Intermediate and Advanced Test and Evaluation certification.

OA4702 Cost Estimation

This course provides a broad-based understanding of the cost analysis activities involved in the acquisition and support of DoD weapon systems. In addition, it introduces Operations Research techniques fundamental to the field of cost estimation.

OA4602 Joint Campaign Analysis

This course studies the development, use, and recent applications of campaign analysis in actual procurement, force structure and operations planning. Emphasis is on formulating the problem, choosing assumptions, structuring the analysis, and measuring effectiveness. Interpreting and communicating results in speech and writing is an important part of the course. In the last three weeks students conduct a broad gauge, quick reaction campaign analysis as team members.

Suggested Electives

OA3411 Introduction to Human Systems Integration

This course serves as the framework for examining Human Systems Integration in the context of Department of Defense Systems Acquisition as mandated by DoD Instruction 5000.2, Enclosure 7. This course provides an overview of the HSI domains: Human Factors Engineering, Personnel, Habitability, Manpower, Training, Environment Safety and Occupational Health, and Survivability. Principles of individual physiological and psychological capabilities and limitations and team attributes are also introduced.

Please refer to Suggested Electives under Systems Engineering Specialisation Track (page C-29) for description of other elective courses.

Specialisation Track: Space Systems Engineering

AE2820 Intro to Spacecraft Structures

Review of statics and strength of materials. Beam theory: axial, bending, shear and torsional loading, stress analysis and deflection of beams. Design of spacecraft structures for launch loads and a survey of typical launch vehicles. Beam buckling and vibration, critical buckling loads, natural frequencies, and mode shapes. Truss structures and introduction to the finite element method.

AE3804 Thermal Control of Spacecraft

Conduction, radiation, thermal analysis, isothermal space radiator, lumped parameter analytical model, spacecraft passive and active thermal control design, heat pipes, and louvers.

AE3818 Spacecraft Attitude Determination & Control

Spacecraft attitude linear control: linearized attitude control, three-axis-stabilized spacecraft. Non-linear attitude control design: minimum-time slewing maneuver, quaternion feedback. Actuators for attitude control: Thrusters, Reaction Wheels, Control Moment Gyroscopes, Magnetotorquers, and related topics (thrust modulation and mapping, CMG steering laws and singularities, momentum dumping). Sensors for attitude and rate determination: star sensors, horizon sensor, sun sensor, gyroscopes. Attitude determination methods: deterministic approach (Triad algorithm), statistic approach (Wabha problem), stochastic approach (Kalman Filter). The labs focus on the practical solution of significant attitude control and determination problems by simulations in Matlab-Simulink.

AE3830 Spacecraft Guidance & Control

Overview of the Spacecraft Guidance, Navigation, and Control System. Sources and effects of navigation and modeling errors on guidance and control systems. Error propagation techniques: linearization of spacecraft dynamical equations, covariance propagation and Monte Carlo simulations. Applications to spacecraft rendezvous and attitude control. Introduction to optimal control theory. Optimal bang-bang control for spacecraft thrusters. Linear-quadratic control problems and feedback control. Selection of weights and performance analysis. Perturbation guidance. Application of the matrix Riccati equation to spacecraft stability, control and guidance.

AE3851 Spacecraft Propulsion

Introduces concepts and devices in spacecraft propulsion. It reviews fundamental fluid mechanics, electricity and magnetism, and thermodynamics with molecular structure. Conventional chemical means such as H_2/O_2 and monopropellants are discussed. Electric propulsion schemes (resistojets, arc-jets, ion, magneto-plasma-dynamic, etc.) are introduced and their performances contrasted with chemical schemes. Characteristics of more advanced concepts (laser, solar, nuclear, etc.) are also considered.

AE4820 Robotic Multibody Systems

This course focuses on the analytical modeling, numerical simulations and laboratory experimentation of autonomous and human-in the loop motion and control of robotic multibody systems. Systems of one or more robotic manipulators that are fixed or mounted on a moving vehicle are treated. Applications are given for under-water, surface, ground, airborne, and space environments. The course reviews basic kinematics and dynamics of particles, rigid bodies, and multibody systems using classical and energy/variational methods. The mechanics and control of robotic manipulators mounted on fixed and moving bases are considered. The course laboratories focuses on analytical and numerical simulations as well as hands-on experimentation on hardware-in-the-loop.

EO3525 Communications Engineering

The influence of noise and interference on the design and selection of digital communications systems is analyzed. Topics include link budget analysis and signal-to-noise ratio calculations, receiver performance for various digital modulation techniques, bandwidth and signal power trade-offs, an introduction to spread spectrum communications, and multiple access techniques. Examples of military communications systems are included.

AE4850 Astrodynamic Optimization

This course develops basic measures of performance of a space vehicle (including launch vehicles) with methods to target a set of conditions and optimize the performance. Topics include an overview of the Guidance, Navigation and Control System, fundamentals of nonlinear programming, state-space formulation, vehicle and environmental models, performance measures, problem of Bolza, the Maximum Principle, and transversality conditions. A significant focus of the course will be in practical methods and numerical techniques, particularly pseudospectral methods. Computational methods will be used to solve a wide range of problems in astrodynamic optimization arising in military space, such as rapid spacecraft reorientation and targeting problems, launch-on-demand, strategic low-thrust orbital maneuvers, and optimal formation-keeping strategies. Where appropriate, the course will illustrate systems aspects of mission design.

AE4870 Spacecraft Design 1

Principles of spacecraft design considerations, spacecraft configurations, design of spacecraft subsystems, interdependency of designs of spacecraft subsystems, launch vehicles, mass power estimation, and trade-offs between performance, cost, and reliability. The emphasis is on military geosynchronous communications satellites. The course includes an individual design project.

ME3521 Mechanical Vibrations

Elements of analytical dynamics, free and forced response of single degree and multi-degree of freedom systems. Dynamic response using modal superposition method. Properties of stiffness and inertia matrices, orthogonality of modal vectors, eigenvalue problem, modal truncation, vibration isolation and suppression. Vibration of bars, shafts, and beams. Supporting laboratory work.

PH2514 Space Environment

Plasma concepts. Solar structure and magnetic field, particle and electromagnetic emissions from the sun, the geomagnetic field, and the magnetosphere, radiation belts, structure and properties of the earth's upper atmosphere, ionosphere, implications of environmental factors for spacecraft design

SS3500 Orbital Mechanics and Launch Systems

Provides a fundamental understanding of Orbital Mechanics through study of conic sections, coordinate systems, coordinate transformations, and time. Calculation of orbital elements of the two-body problem is covered. Other Orbital Mechanics topics include: Newton's laws, Kepler's equation, orbital perturbations, and orbital maneuvering, including rendezvous and proximity operations. Launch systems topics include: the rocket equation, single and multi-stage rockets, launch windows, launch profiles, ascent and payload delivery performance, and mission design. Supporting lab work utilizes the Satellite Tool Kit (STK) as an orbit analysis tool. The use of Excel and / or MATLAB for solving problems is encouraged.

SS1100 Intro to Programming for Space Applications

An introductory course to programming for space applications. Basic concepts of programming are considered, as well as matrix operations, vector and matrix manipulations, symbolic processing, printing, and plotting using MATLAB. Simulink modeling basics and the Communication Systems Toolbox will also be introduced. This course prepares students for programming and using Simulink in future course work in Space Systems Operations.

AE4830 Spacecraft Systems 1

This course emphasizes the systems analysis of geosynchronous spacecraft and covers the analysis of GNC (orbit and attitude control), structures, propulsion, thermal and electrical power subsystems. Basic mathematical equations will be used in the preliminary design of the subsystems and the tradeoff studies involved. The differences and similarities between dual-spin and three-axis stabilized spacecraft will be covered in detail. Systems aspect of a typical mission profile will be illustrated. Throughout, emphasis will be on the spacecraft bus. Students will be engaged in problem solving during most of the laboratory period.

AE4831 Spacecraft Systems 2

In this course, students will be involved in a group project to design a spacecraft to meet mission requirements. Material presented in AE4830 as well as AE4831 will be utilized. In parallel, this course covers some or all of the following aspects of spacecraft systems: spacecraft testing, TT&C subsystem, and design of observation payloads. Differences and similarities between geosynchronous spacecraft and LEO/HEO spacecraft will be discussed. Topics include gravitational perturbation (J2 effects), gravity-gradient stabilization, and atmospheric drag effects.

IS3502 Network Operations I

This course introduces the basics of network operations. Topics covered include but are not limited to configuring and managing networks, routers, and servers (file, e-mail, web, DNS, printer, etc.); network monitoring and traffic analysis; storage and bandwidth allocation; quality of service, performance monitoring and analysis; deploying and managing firewalls and malware/intrusion detection/prevention systems; configuring access controls; managing and retaining logs; setting up VPNs and secure connections; business continuity and disaster recovery planning; managing software patches; and network policy and compliance.

NS4677 Space and International Security

This course studies the political history of the space age from the perspective of U.S. national security, as well as U.S. relations with other major, space-faring countries. It also covers arms control treaties, legal issues, international negotiations, and space management questions from a current policy perspective. An independent research paper or policy memo on an assigned topic is required.

PH2514 Space Environment

Plasma concepts. Solar structure and magnetic field, particle and electromagnetic emissions from the sun, the geomagnetic field, and the magnetosphere, radiation belts, structure and properties of the earth's upper atmosphere, ionosphere, implications of environmental factors for spacecraft design.

PH3052 Remote Sensing

This interdisciplinary course explores the physical principles underlying the sensor systems needed for satellites and tactical aircraft, as well as limitations imposed by the atmosphere and operating environment on these systems and their communication links. Topics include: satellite orbits, the satellite environment, ionospheric interactions and atmospheric propagation, phased array and pulsed compressed radars, imaging synthetic aperture and inverse synthetic aperture radars, noise resources, thermal radiation, principles of semiconductor devices, optical and infrared imaging detector systems, and their resolution limitations and bandwidth requirements.

SS3011 Space Technology & Applications

SS3011 is an introduction to space mission analysis with an emphasis on those space missions supporting military operations. Topics include space history, doctrine and organizations, orbital mechanics, communication link analysis, the space environment, spacecraft technology and design, and military, civil and commercial space systems.

SS3400 Orbital Mechanics, Launch and Space Operations

This course provides an understanding of Orbital Mechanics and the associated implications to the use of space-based systems in support of military operations. Fundamental concepts such as conic sections, coordinate systems, coordinate transformations and time are covered, then applied to the understanding and application of Newton's laws, Kepler's laws, orbital elements, perturbations, and orbital maneuvering.

SS3600 Space Systems Modeling & Simulation

SS3600 provides students with knowledge of modeling and simulation theory and the ability to apply space systems modeling and simulation tools to real world problems. Concepts covered include the development and applicability of models and simulations, with a focus on specific space applications. Students will apply these concepts through laboratory exercises and a project to simulate an end-to-end space architecture, evaluate system performance, and compare alternative solutions.

Guide for International Applicants

1. Immigration Matters

1. Offer of Admission. International students who are successful in gaining admission to the full-time MSc programme must note that their offer of admission is conditional upon the successful application of their student passes.

2. SOLAR. The Immigration & Checkpoint Authority (ICA) has implemented a web-based system for student pass application called the "Student Pass On-line Application & Registration" SOLAR. When full-time international students have been offered admission to our programme, the University will proceed with the student pass application via SOLAR and also write to inform candidates how to complete the application process at their end. After candidates accept the offer through SOLAR, ICA will process the application.

3. For candidates from countries who require a visa to enter Singapore, the University will be applying for the visa cum student pass via SOLAR. If the student pass application is approved, the In-principle Approval (IPA) letter, which also serves as a single-journey entry visa will be sent to the relevant candidates. This letter and the valid passport must be presented to the Duty Officer at the Immigration checkpoint upon arrival in Singapore.

4. For candidates from a non-visa required country (e.g. USA), you can collect the approval letter at the point of registration with the University.

5. Application for Student Pass. On your arrival in Singapore, you will be given a Social Visit Pass for a minimum of 2 weeks at the airport or point of entry. You may be asked to show your Letter of Admission. After registering as a student and obtaining your student registration card, you must apply for a Student Pass at the following centre:

Immigration and Checkpoints Authority (ICA) ICA Building 4th Storey, 10 Kallang Road Singapore 208718 Contact: 63916100 http://www.ica.gov.sg	• Make an e-appointment at the ICA website (http://eappointment.ica.gov.sg/) before going to ICA Building • Your passport will be returned within 1-2 weeks • Bring along your Letter of In-Principle Approval (with Temasek Defence Systems Institute's endorsement) • *Some applications for student pass may take a longer duration to process. In some instances, the processing time may take up to 6 weeks. For such situations, the candidate's Social Visit Pass will be extended by ICA accordingly.*

6. Application for Social Visit Pass. Please note that spouses and/or children of international M.Sc. students are not sponsored by the University for their VISA applications. Application of their Social Visit Pass (SVP) has to be made directly at the Visitor Services Centre, 4th floor Immigration and Checkpoints Authority (ICA) and a bond is required. The amount of the bond is to be established by ICA. Student must have already obtained a Student Pass issued by the ICA at the time of application. A local sponsor *(Singapore Citizen/Permanent Resident)* is required in order to apply for a SVP for spouse and/or children. The SVP granted will normally be for up to a maximum period of 6 months. It is renewable, subject to ICA's approval.

7. Details on immigration matters can be found at the Immigration and Checkpoints Authority website at *http://www.ica.gov.sg*

2. Accommodation

The Office of Student Affairs (OSA) will provide assistance in locating suitable accommodation. Information on how to apply for accommodation will be mailed to students after they have been offered a place at NUS. More details are available at
http://www.nus.edu.sg/osa/has/graduate/application-guide

3. Estimated Cost of Living

An International student can expect to incur the following monthly expenses excluding course fees:

Expenditure (per month)	Single
NUS Graduate Student Residences	
On-campus: PGPR Graduate Student Apartments	S$1000 - S$2000
Off-campus Private Accommodation	
Room Rental	S$600 - S$1000
Apartment Rental	S$3000 upwards
Food	
University Canteens / Food Courts	S$300 - S$400
Meals Outside Campus	S$500 - S$700
Books / Supplies	
Depends on course of study	S$150 - S$200
Transport	
Public bus / MRT	S$150 - S$200
Personal Expenses	
Toiletries, clothing, groceries, entertainment, etc	S$500 - S$600
Miscellaneous Fees (subject to review)	
Medical Insurance	S$65 per semester

Note: The costs have been derived based on a conservative estimate for a reasonably comfortable lifestyle. The actual amount could be higher or lower depending on the individual student's expenditure and lifestyle patterns.