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Naval Postgraduate School: Tech Bridge to the Future Fleet

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NAVAL POSTGRADUATE SCHOOL: TECH BRIDGE TO THE FUTURE FLEET

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Ask not what the Fleet can do for you,
Ask what you can do for the Fleet.

With their superior mobility and global reach, U.S. Naval forces are the preferred means of U.S. and Western power projection. But in this era of high-speed weapons and near-instant communications, projection in space alone may no longer be sufficient to ensure the primacy of Allied power. The ability to project power forward in *time* as well as space will become increasingly mission-critical to maintaining our Super Power status.

As the Navy's graduate research university dedicated to preparing officers to command this Space-Time High Ground, and to conceiving, designing and testing every aspect of the Future Fleet, the Naval Postgraduate School is the nation's answer to this vital national security requirement. Every day, NPS faculty-student teams exercise what Einstein held to be the faculty even more important than intelligence – imagination. They *envision* what Naval technology will be like twenty and more years into the future, *and then bring it into reality.*

The following "HoloDeck" scenario envisions a 'typical' day on board a surface ship in the year 2020 based on research underway *today* at the Naval Postgraduate School. If it sounds futuristic, that's just the point. The basic and applied research to make every aspect of this future vision a reality – from writing the software for Network Centric Warfare and shipboard wireless area networks, to beaming courses to distance learning students while deployed, to integrating satellite feeds into 3-D simulations for just-in-time on board training -- is going on *right now* at NPS.

- Although a Navy command, the Naval Postgraduate School (NPS) provides graduate-level military education to commissioned officers from all U.S. military services, allied military services (currently 247 students from 47 nations), and their civilian service equivalents. In keeping with the focus of *Proceedings*, this article emphasizes that portion of NPS' mission and research of particular relevance and interest to the Naval Service. Officer student ranks are at time of graduation.

USS ERNEST J. KING (MCS 75) (Multi Capable Ship)
LOCATION: South China Sea
TIME/DATE: 0100Z - 25 December 2020
MISSION: Littoral Patrol, Contingency Ops

As our scenario opens, Captain Christopher ("Chris") Williamson is in his quarters on board the *USS Ernest J. King*, a newly commissioned, fully digitized blue-and-green-water trimaran hull Littoral Projection Destroyer with seamlessly integrated automatic controls and a crew of 90. (The Land Attack designator was dropped a decade ago for geopolitical reasons). Williamson earned a Masters and a Ph.D. degree as a young lieutenant while operationally deployed as an ASW helicopter pilot -- one of NPS' Distance Learning Program pioneers -- in 1999-2001.

The Commanding Officer, wearing the standard issue 3D heads-up display visor and audio headset with noninvasive electrodes for bio-monitoring and computer-crew comms, is watching his children play in front of the Christmas tree on the holoscreen. Though not yet Christmas Day in San Diego, the entire crew has already had a chance to visit with their families. Now it's his turn. As he begins to talk to his wife, a "Secure Override" with Seventh Fleet crest flashes over the image of the crackling fire on the screen.

Captain: **Honey, I've got to go. Seventh Fleet's breaking in.**
Wife: **On Christmas? OK, OK. Duty calls.**

Seventh Fleet breaks in on the screen.

Admiral: **Merry Christmas, Chris. How are you doin'?**
Captain: **Fine, Admiral.**
Admiral: **Chris, we've got a mission coming up – PACFLEET directed -- off the Spratley Islands. I need you to go over there and get in place. Seems some kind of trouble's brewing over a piece of real estate the size of my backyard. Some people never get over a grudge, I guess. But it keeps us in business. Right?**
Captain: **If you say so, Admiral.**
Admiral: **Listen, Chris. Bring up the PACFLEET Command Center screen for specifics. They're implementing JTF BRAVO, with everything you'll need for intel support. We've set up a secure web site – the address should be on your screen –**
Captain: **Yes. Got it.**

Admiral -- where you can enter all the info you'll need. I've begun notifying the appropriate people. I want you to put together an Ops concept, and I'll need it quick. Do you think you could have it for me in a couple of hours?

Captain: Yes, Sir. You'll have it before then.

Admiral: Good.

After studying the Mission Brief and 3D holographic map, the Captain wireless-modems an Ops plan to Seventh Fleet, in less than an hour. The Admiral accepts the plan and forwards it to CINCPACFLEET. As he leaves his cabin, Williamson touches a button on his visor and speaks into his headset, issuing an order directly into the headphones of all warfare commanders, including the Marine Special Ops detachment's, to meet him immediately in the Ship Control Center (SCC). On the way, all the while talking the Ops Plan brief into his headset for the benefit of the commanders assembling below, he looks in on the Auxiliary Bridge.

Captain: ***Only two men on this Auxiliary Bridge, and the whole thing no bigger than a 747 cockpit. And my entire crew -- less than a hundred men. I can remember when ships this size had three times that crewing level. What's driving all this, of course, is time – or the lack of it. With a quarter second to geosync orbit and back, and sea skimming missiles at Mach 2, reaction times can be on the order of seconds. Or less.***

As he looks in, the synthesized Automatic Bridge-to-Bridge voice sounds. ***"USS Ernest J. King, U.S. Merchant Ship 'White Knight' on your starboard bow at eight nautical miles. I show us crossing your bow at six nautical miles. Please state your intention."***

Captain: Better respond to that right away.

Officer of the Deck: Aye, Aye, Sir.

As the Captain enters the Ship Control Center below deck, the Department Heads rise. Three large holographic command screens fill the far wall, with a half dozen smaller consoles manned by as many officers – the full watch contingent – off to one side. He scans the room, comparing what he sees to what it used to be like.

This 'Three-in-One' Integrated Ship Control Space is amazing. It does everything the old Main Bridge, Integrated Bridge System/Combat Information Center and Engineering Main Control used to do, and more – its vast array of sensors and comms so automated and seamlessly integrated that a handful of people can keep track of everything: monitor traffic under, on and above the sea, uplink and downlink intel, tune the ship's 'intelligent' materials to manage her electronic signatures, and navigate, pilot and fight the ship. Whatever's needed. Onboard machinery, including power plant, is mostly unmanned and automatically monitored, along with all weapons and sensor systems, compartments, hatches, tubes, crew bio-states, even alertness levels – with all data fed and integrated into this single Ship Control Center. And all with a watch of only five or six – one quarter of what it used to be. Everything depends on them. In most crises, the time to call General Quarters won't be there – all the initial responding has to be done by just these five or six men . . .

Captain: Carry on. You've all heard the Ops Plan brief?

Dept. Heads: Yes, Sir.

Captain: Good. We might have to go in to shore. MarDet CO, activate Virtual Environment Compartment 3 - 22 - 6 - LIMA so your Ops guys can get some 'ground truth' ahead of time. JTF BRAVO's cleared to support you. They'll down-link all satellite imagery and data you'll need to set up the sim-train with 3D visuals, temps, humidity – whatever. And don't forget the treadmills. Your guys need to get exercise, you know.

MarDet CO: Yes, Sir. They'll appreciate that.

Captain: The helo crews can set up in Virtual Chamber 2. Same thing. Go to JTF BRAVO to downlink your holo-surrounds from the dish.

Air Boss: Yes, Sir. We'll get right on it.

Captain: On intel, we've received the Op Order and ROE to fly micro birds out over the island. And be sure and get right on it, so we can beat the BRAVO satellite feeds for those sim-trains.

Weapons Officer: I'm giving the 'go' to launch Micro UAVs, Sir. (Into his headset): Officer of the Deck, Op Order has been received to launch 100 birds to target. Check JTF BRAVO for your GPS settings and get them to the launch crew.

Weapons Watch Officer: Aye, Aye.

On deck, the launch crew check their wristband screens to get GPS coordinates on a hundred Micro Unmanned Aerial Vehicles -- some the size of sparrows, some of dragonflies -- before popping them into eject pods on the 'mother' UAV being prepared for take off. Powered by microwaves picked up by whole-body 'antennae' after being released from the craft once it closes in on the island, they will swarm off towards their pre-designated surveillance targets. Shortly, they will pass and hover over the Ops area, jamming island radar and sending back video and audio telemetry automatically fed into the GCCS, the Integrated Shipboard Control Center, and Sim-Train compartments to complement the BRAVO-cleared satellite imagery.

Captain into headset: Boats, you get the right coordinates on those UAVs?
Boatswain: Flying like birds, Captain!
Captain, pulling up an image of the aft deck on one of the holoscreens:
Good. ***These things look more and more like real birds and insects. When I was a lieutenant -- like him -- we had little choice but to send in a man 'live'*** **. . . We got feeds back yet from any of those birds?**

Chief: **Yes, Sir. We've got Number 7. I'll put it on Screen 2.**

Captain: **Send a signal to 7 to zoom in on Target 10, at 200 meters.**
(The image on the screen suddenly enlarges). Right. We want to avoid that area. Get a snap on that and put it up on the Mission web page to 7th Fleet.

Chief: **Yes, Sir. . .Done, Sir.**

Captain: **I want our UAVs to check out the proposed landing area for mines. We don't want anything to happen to our friends down in Sim-Train.**

Lt.: **Roger. Sir, do you want a METOC predict on that?**

Captain: **Right. What does the approach and surf zone look like at one and two days out?**

Lt.: **Both are 'Go's', Sir. I'll put it up on holoscreen 1. You can see, there's a weak tidal beam and some cross currents, but nothing major.**

Captain: ***Twenty four hours is nothing these days. METOC predicts out two weeks now.*** **How about the weapons systems?**

Lt.: **All weapons system sensors 'go,' Sir. Anti-missile laser tested out fine last week. Same with the EM railgun.**

Captain: **Good.**

Below deck, a Marine Squad in full gear are sweating on omni-directional treadmills in hot, humid Virtual Compartment 3, walking 'through' a 3D holo-surround of the island 200 nautical miles away, integrated from satellite downlinks and the Micro UAV feeds.

1st Marine, wiping his brow: There's nothing 'virtual' about this *heat!*
2nd Marine: You can say *that* again. I sure hope the Captain doesn't try to double time us through this stuff. Last time I was on one of these things and they did that, I almost broke a leg, when we went around a 'bend' in one of these trails. It's scary how real this is. You *sure* we're not on that island?
1st Marine: I don't think so. Not yet. I agree. This is plenty real for me!

Captain into his headset, in the SCC: Chief Engineer, how's it goin' down there? Checked the area search and damage control robots yet?
Eng.: Yes, Sir. We're a 'go' down here, Captain. Ran three fire drills - set the 'fire' in random compartments – and they all responded. I also ran an all-systems diagnostic, and our only lifecycle problem readout is on bearing 3 – 15 hours.
Captain: Can't change Number 3 yet. I want to try to get at least 48 hours out of this thing.
Eng.: Roger. I'll leave it, Sir.

Captain: *Thank God we've never gotten hit! – thanks to this new 'flinch' system. If we fire at an incoming and miss, it automatically calculates where it's likely to hit and activates the systems needed to ready the ship to minimize damage. Automatically closes doors and valves, reroutes the fire main, turns on sprinklers – whatever's needed to optimize survival – and victory.*

Captain to Ship Control Center Watch Officer: We'd better run a General Quarters drill.
SCC Watch Officer (into his screen): Officer of the Deck, this is SCC. Set General Quarters.

He pushes a button to activate the synthesized voice of the Integrated Shipboard Control Computer and feed it into the ship's intercom. Bongs and 1MC ring out.

Computer: General Quarters. General Quarters. All hands fix visor headsets and man your battle stations. General Quarters. All hands fix visor headsets and man your battle stations.

Once the computer remotely confirms the shipboard locations and headset electrode placements for all crew -- in less than a minute – the Voice disappears off the intercom.

Computer to all headsets: Remember to move forward. All hatches will automatically close in three minutes. Repeat. Move forward. All hatches will automatically close in three minutes.

Computer to Captain's headset: Captain, we have a problem with Hatch 4. The hatch is not shut. Notifying Repair 3 to send runner.

Computer to Repair 3: Hatch 4 is open. Your route is on your heads up holo-display. Please confirm.

Repair 3: Check. Display is up.

Computer: You have three minutes to get to Hatch 4. Temperature and gas readings are normal in all spaces along your route.

Repairman at Hatch 4: Man! Who left that swab in here?! ***He removes it and closes the hatch, hitting a visor button.*** **Computer, try Hatch 4.**

Computer: Hatch 4 is secured. Captain, ZEBRA has now been set.

Captain, in the SCC: ***It never ceases to amaze me. ZEBRA used to take seven minutes -- <u>if</u> there were no glitches.***

SCC Deck Watch Officer: Captain, we have incoming from Seventh Fleet.

Admiral on Holo-screen 2: Chris, hold tight. This whole thing may be called off.

Captain: That'd be great, Sir. My guys in Sim Chamber would sure like to get out o' there. Seems the heat's pretty real down there.

MarDet CO, flashing a thumbs up: You mean *my* men, Sir.

Admiral: That's right. Semper Fi, Major. Give 'em a break. I'll keep you posted, Chris. I just talked to III MEF Commander, and he'll be contacting you. Remember, he ran the last JTF like this.

Captain: Roger, Admiral. Out.

After getting some fresh air on deck, the Captain stops by the Shipboard Distance Learning (DL) compartment, where an ensign is carefully studying one of a dozen touch-screen 3D consoles.

Captain: **How's it goin', Ensign?**
Ensign: **Fine, Captain. Test tomorrow – Comp Sci.**
Captain: **What's the school?**
Ensign: **NPS Virtual Campus, of course. Really no other choice, Sir. Not if you want it tailored to the Fleet, and your job. And piped in when you want it.**
Captain: **It's working out for you, then?**
Ensign: **Yes, Sir. I want to earn a degree, so I spend all my spare time down here. Besides, I can apply what I learn in my duty assignments, sometimes the very next day.**
Captain: **What about the equipment? Is it working?**
Ensign: **Yes, Sir. These wireless modems are great. I think they resulted from a thesis at NPS, Sir.**
Captain: **I think you're right. Well, good. Carry on. And good luck.**
Ensign: **Thank you, Sir. I'll need it.**

As he returns to his cabin to check the SIPRNET, the Captain recalls with satisfaction, and pride, his own days as one of the first graduate student in NPS' Shipboard Distance Learning Program, in Software Engineering, which he was able to keep up with while deployed-underway, even during RIMPAC. Now – maybe – he'll have time to get back to his family and Christmas . . .

*** * ***

Now, back to 2000.

The scope of defense-vital research at NPS is so great that the best way to grasp its central importance to commanding the Space-Time High Ground is to review some outstanding examples of what our officer students are actually doing, and have done, to build the leadership, ships and systems of the Future Fleet. These examples are selected from thousands of Masters and Ph.D. theses and faculty research programs over ninety years of Naval Postgraduate School history and are not intended to be exhaustive. Rather, they have been chosen to 'flesh out' the above scenario and give the reader a command view of the School's strategic importance to national security.

Deserving Victory: Training the Navy's Future Leaders

NPS was created nearly a century ago by some of the finest minds in military planning. Its origins date back to World War I, when the urgent need for advanced officer training to increase the combat effectiveness of U.S. Naval forces was first realized. Fleet Admiral Ernest J. King and others who pressed this conviction saw their vision vindicated when a new cadre of highly-trained officers formed the leadership that led to victory in World War II.

"Your entire education at NPS is geared toward becoming a leader – learning to make the right decisions at the right time in an increasingly fast-paced, high-tech environment," said Cmdr. Jerry Becker, a graduate of the National Security Affairs/Naval Intelligence curriculum.

One of the surest indications of the importance of the Naval Postgraduate School to the Future Fleet is its central participation in the CNO's Stratetic Studies Group (SSG). Each year, six NPS and six Naval War College officer students are selected as Associate Fellows, participating in a high-level, six-month strategic review of the technologies and issues determined to be of greatest importance to the Navy over the next 30 to 50 years. Another sure indication of the strategic value of an NPS education are the testimonials of graduates who have risen to the highest ranks and made the greatest contributions to the Service **(see "NPS: A Strategic National Investment," pg. --).**

Graduate defense-oriented education, in fact, is fast becoming a prerequisite for promotion to flag rank, with NPS leading the way. As of 1997, one third of the 21 one-star flag officers selected for promotion to rear admiral (upper half) were NPS graduates. And in almost every competitive category and grade, officers who have attended or are attending NPS fare better than the Fleet average in selection for promotion.

This emphasis on graduate education for the Navy's leadership is growing, and has recently been extended to all Sailors. In July 1999, CNO Adm. Jay Johnson sent a message to all commanding officers calling for incorporating higher education into *every* naval career, making lifelong learning a strategic priority and reality for both officers and enlisted. Under the CNO's guidance, new programs are being initiated that will give every URL, RL and Staff Corps officer the opportunity to obtain a graduate degree and professional military education (PME) relevant to his or her duty assignments.

Toward this end, NPS has partnered with the Naval War College's College of Continuing Education, which has a campus on base, to offer all NPS students the three-course NWC program in conjunction with their masters degree curricula, leading to a Naval War College Command and Staff diploma meeting the requirements for intermediate level Navy Professional Military Education (PME) and Joint Professional Military Education (JPME) Phase I. This is especially important as, without required PME/JPME, promotion beyond 0-6 is not allowed. NPS has also partnered with the Naval

Academy, offering its company officers a Leadership Education and Development Systems Management curriculum. In addition, the School is on track with the Massachusetts Institute of Technology (MIT) to become one of five core academic partners in the innovative Product Development for the Twenty First Century (PD21) Program. In these and other partnerships, the Naval Postgraduate School is recognized as a world class institution of higher learning, as evidenced by its recent *maximum* ten-year reaffirmation of accreditation by the Western Association of Schools and Colleges (WASC).

Reinventing the Fleet

With the end of the Cold War and downsizing of defense budgets, the number of active Navy ships has declined more than 40 percent in less than a decade, with major efforts still being made to reduce crew levels in the remainder of the Fleet.

In 1996, the Navy initiated the "Smart Ship" program, in which a limited number of 'test-bed' ships were upgraded with the most advanced technical innovations, enabling reduced manning. After much 'reshaping,' however, the first "Smart Ship," USS Yorktown (CG 48), has been able to reduce its crew level relative to other cruisers by only 15 percent. Yet the Navy's goal for the year of our Future Scenario, 2020, *is more than four times that much -- a 70 percent manning reduction over current crew levels for a comparable surface combatant, from 360 to about 100 personnel.* Such radically reduced manning targets clearly will not be met merely by 'reshaping' existing ships, even were such innovations to be applied Fleet wide. They can only be met by designing completely new surface ships 'from the keel up,' maximally leveraging the productivity gains afforded through advanced information technology (IT).

Seeing this clearly, the Naval Postgraduate School has responded to the challenge. In our Total Ship Systems Engineering (TSSE) program, officer students design entire 'future ships' – like the one in our scenario -- to meet specific Navy needs. Initiated in 1991 by Director and Mechanical Engineering Professor Charles Calvano (Captain USN, Ret.), the curriculum is sponsored by the Naval Sea Systems Command -- the Navy activity responsible for the design and procurement of all Navy ships, including combat and weapons systems. It provides a broad-based, design-oriented education focusing on the warship as a total engineering system, including hull and mechanical, electrical and combat systems. A TSSE graduate, Lt. David Ruley, did the artist's conception of the visionary surface combatant in our 2020 scenario (pg. --). Working in interdisciplinary teams, students from Mechanical Engineering, Electrical Engineering and Combat Systems/Physics use the Navy's Advanced Surface Ship Evaluation Tool, an early-stage design program, to literally reinvent the Future Fleet.

"An interdisciplinary systems approach is absolutely essential to ensure that ships' weapons and sensors are fully integrated with the mechanical and electrical systems that

support them, that subsystems don't work at cross purposes to one another, that design trade-offs are optimized, and that the overall ship design is as broad-based and versatile as possible and still meets the Navy's specifications," Calvano said. "Our future ships must be survivable yet versatile, because we don't know what the emerging threat will be."

Student Total Ship designs have been briefed to the Assistant Secretary of the Navy for Research. Development and Acquisition, and a number of TSSE graduates now play key roles in the Navy's ship acquisition programs.

Inventing New Shipboard Power Sources for the 21st Century

Changes in propulsion systems – from sail to steam, propeller to jet engine, and nuclear power -- have fundamentally changed the nature and power of naval forces. The latest advance is electric drive technology with integrated power architecture, whose key element is a single source generator to meet all of a ship's power needs, including propulsion. The new technology will significantly reduce the cost, noise and maintenance demands of how ships are driven; allow for major changes in ship design, reductions in manpower, and the allocation of more power to warflighting applications; and vastly improve shipboard quality of life with increased space for state rooms for all crew members.

In the NPS Propulsion Laboratory and elsewhere on campus, student-faculty teams are experimenting with this and other new power and power-distribution systems under the Surface Combatant 21 Program. They have designed direct current electric drive and "zonal electric distribution" systems which eliminate the need for a shaft, in turn allowing for compartment and equipment placements that reduce the probability of damage from enemy hits. "There are a lot of 'golden beebees' on a surface ship," said former student Lt. Jean, "and you can eliminate a lot of them and maximize stability and survivability by design changes you're freed up to make once you've gotten rid of the shaft. And with electric drive propulsion, if you take a hit you'll be able to instantly reroute power and reconfigure the ship to continue to fight."

"The biggest advantage of going to direct current power systems is survivability," said Electrical and Computer Engineering Professor John Ciezki. "DC distribution and electric zoning, which breaks a ship up electrically into nine or ten different zones, gives better capability to ride through hits and faults and keep your systems on line."

Mechanical Engineering student Lt. John Comar has also experimented with using fuel cells for a surface ship's primary power source, building and optimizing different fuel cell models using the Advanced Surface Ship Evaluation Tool. And Aeronautics and Astronautics Distinguished Professor Max Platzer received a patent for his invention of a new integrated propulsion-lift control system applicable to both ships and aircraft.

NPS' Department of Aeronautics and Astronautics has Gas Dynamic, Combustion, and Turbo Propulsion Laboratories; the Department of Electrical and Computer

Engineering includes a Power Electronics Lab; and the Mechanical Engineering Department boasts a Gas Turbine and Diesel Propulsion Laboratory.

This January 6, the Navy announced the Land Attack Destroyer (DD 21) will be the first class of ships to be powered by electric drive technology with integrated power architecture. "DD 21 will truly be the first 'Smart Ship' built from the keel up," said Secretary of the Navy Richard Danzig.

"Smartest" Ship in the Fleet

In a very real sense, the Naval Postgraduate School is itself the lead "Smart Ship" in the Fleet. It does more applied research than any other DoD university and leads the nation in long-term, basic research on the processes of warfare as a system. Honing new technologies through proof-of-concept experiments, prototypes and testing, the School's faculty-student teams are the "Tech Bridge" to breakthrough tactical advances in the Future Fleet. Its research labs are state-of-the-art 'test beds,' and its degree programs are continuously adapted to meet the changing needs of the Service and Department of Defense. NPS officer students arrive with direct knowledge and experience of Fleet needs, making them the perfect vehicle to bring "Tactical to Technical" -- and to take Technical *back* to Tactical upon graduating from a rigorous academic program that includes solving real-time warfare problems of direct relevance to the Navy.

"This 'crucible' of technical-tactical interaction is an ongoing and routine part of the academic environment at NPS," said Provost Dr. Richard Elster. "It takes years to build and blend academic expertise with military applications to produce productive results; and, every year, our faculty and students provide 250 man-years of advanced research in support of Navy goals and future warfare development. In all these regards, NPS is absolutely unique."

Like a "Smart" Ship, NPS is constantly re-engineering her mission-critical activities – graduate education and research -- as well as her laboratory and IT infrastructures, to be as state-of-the-art, cost-effective and manpower-efficient as possible. And like any ship at sea, interaction between 'crew' peers is an essential, if not central, part of the culture and training.

"Half or more of my NPS education came from interacting with other military members 'who've been there,'" stressed Cmdr. Jerry Becker, a graduate of NPS' National Security Affairs/Naval Intelligence curriculum. "To maintain your professional edge these days, an officer has to be committed to continuing his education. Being immersed in an environment like this, where you're constantly working with military peers, is an integral part of that education – one which you simply can't get anywhere else."

Making Network Centric Warfare a Reality

With decreases in manpower, weaponry and budgets, future Navy warfighting will need to be far more efficient than it is today. To achieve that efficiency, the Reduced Crew Ship of 2020 will need to rely heavily on distributed Cooperative Engagement Capability (CEC). This theater air defense capability allows a group of ships to quickly process and share target data, and launch a defending missile before an enemy weapon crosses the defending ship's radar horizon.

One of Professor Calvano's Total Ship Systems Engineering students, Lt. Thomas Jean, recently brought this Network Centric Warfare capability a giant step closer to reality. Jean's proof of concept thesis translated the vision of Cooperative Engagement Capable Distributed Combat Systems (CECDCS) into design goals specific enough that a robust multi-sensor-fused advanced distributed engagement system can now be developed. He showed that the bandwidth is already available to integrate additional Commercial Off-the-Shelf (COTS) sensors -- infrared, sonar, and an ECM suite -- into existing integrated radar systems; and that large numbers of minimally manned, individually less capable but less expensive pllatforms networking sensors, fire control, and command-and-control can perform as a single fighting pod with enhanced collective performance in all warfare areas.

"The current AEGIS system takes a lot of human interpretation to identify friend or foe because it networks only one type of sensor, fire-control-quality radar," Jean explained. "When you add the other modality sensor data into a cross-platform CEC-like network you get faster and better cross-pod target ID and target evaluations. This can make all the difference in a hostile environment where reaction times are getting shorter and shorter. My major contribution was to show that this proposed new force structure can do a lot more for less (cost) to the Navy. By configuring it this way, you get the fighting power of 180 ships vice the current 106. "

"Lt. Jean brought together the experience gained in networking ships for air defense and submarine defense, and projected it forward two decades into the future" – the time frame of our scenario – according to his thesis advisor, Professor Mike Melich of NPS' Physics Department. "It's the Lt. Jeans of the world who reduce the metaphorical flourishes of planning staffs to actual Fleet practice, and drive real creation in the research, development and naval construction communities. Without such skilled people, schooled in the ways of the Fleet and informed in the ways of technology, business and economics, our future Fleet would look little different from the one we inherited from World War II."

A major barrier to robust Cooperative Engagement Capability is the problem of 'sensor fusion' -- how to integrate multi-path, multi-rate, multi-resolution, multi-spectral, often asynchronous data from a wide array of sensors, and feed them into weapons control systems robustly enough to be successfully used by warfighters. A faculty-student team led by Operations Research and Aviation Safety School Professor Kip Krebs (former Lt., USN) is 'fusing' the best data from night vision devices and Forward Looking Infrared (FLIR) sensors into a single image to improve situational awareness for night and low-light operations. "Each sensor has its advantages and disadvantages," explained Capt. Matt Sampson, USMC, a helicopter pilot and one of Krebs' students. "By fusing their outputs, you capitalize on the strengths of each. We're working with the CNO's Aviation Air Warfare Office, looking at ways to improve targeting capabilities on the F/A-18 and improve piloting and navigation on the Cobra helicopter." Other students are working on improving the Navy's Phalanx Close-in Weapon System, testing stabalizers that keep its FLIR steady as it is being aimed.

Also with applications in air offense and defense, Capt. Matt Howell, USMC, researched how to upgrade the Marine Air Command and Control System to a joint full-battlefield-awareness system compatible with the Global Command and Control System for controlling Corps air defense assets and planning and coordinating sector air operations with those of other services.

Fast, secure, reliable broadband data links are the backbone of future Cooperative Engagement Capability and Network Centric Warfare. The current state-of-the-art, high-data-rate global satellite communications system that gives operational commanders near-instantaneous voice and video links, distributes enhanced intelligence imagery to ships throughout the Fleet, and makes it possible for Sailors to 'call home' -- CHALLENGE ATHENA -- was developed by Lt. Cmdr. John Hearing while an officer student at the Naval Postgraduate School. The system, which uses all-COTS components, also supports the video teleconferencing needed for shipboard Distance Learning highlighted in our scenario. CHALLENGE ATHENA was the most significant boost to morale in my 25 years of naval service," said then Commanding Officer of the USS George Washington Capt. Robert Sprigg, now Rear Admiral. NPS' Fleet Wireless Working Group and students Lt. Robert Moss and Lt. Stephen Tripp recently combined a 'loosely coupled components' software architecture with GPS devices to create wireless shipboard computer-to-computer communications, including wireless Internet access. Their proof-of-concept system has a wider bandwidth than either the currently used Naval Tactical Data System (NTDS) or LINK 11. Also this year, Professor Xiaoping Yun and his students Lts. Mark Matthews, Mark Roemhieldt and Kurt Rothenhaus set up a wireless Local Area Network (LAN) connected to wearable mobile computers on board the aircraft carrier USS Harry S. Truman. NPS is a key participant in a multi-year cooperative research effort on Adaptive Architectures for Command and Control for Network Centric Warfare, and recently partnered with the Naval War College and Third Fleet in a four-day

pre-game rehearsal for "Global Wargame 1999" at the School. The School is also teamed with Third Fleet's Network Centric Innovation Center and sea based battlelab, USS Coronado, to identify, develop and test new IT/C4I systems and innovative practices.

Improving Interoperability and Jointness

Interoperability and jointness are the foundation of Network Centric Warfare and Cooperative Engagement Capability. "If you look at the latest national defense panel, they're not simply talking about joint battle labs and joint acquisition. There will be an even greater push for increased interoperability in the future, and NPS is focusing on that future," said Rear Adm. Herbert Kaler, Deputy Director of the Joint Theater Air and Missile Defense Office and an NPS graduate.

Responding to this emphasis, the School has a growing number of facilities, curricula and research programs directly addressing DoD's increased emphasis on interoperability and joint readiness. NPS is the first non-operational site to receive the joint Global Command and Control System (GCCS), allowing faculty and students to actively participate in actual Fleet and field operations and exercises with state-of-the-art battlespace awareness. The thesis work of Capt. Mike Coleman focused on protecting the GCCS from information overload using an automated software analysis tool.

In June 1998, the NPS Program for Joint Education received full accreditation by the Process for Accreditation of Joint Education (PAJE). The School established the Institute for Joint Warfare Analysis (IJWA) to refocus research toward an interdisciplinary, joint approach, resulting in new research proposals such as "Joint SATCOM Architectures" and "Joint Combat ID Testbed Development." IJWA also designed a JPME Phase I accredited Joint Warfare Analysis curriculum to provide joint operational officers with the technical and analytical skills needed to integrate advanced technologies and forces under rapidly evolving conditions. Graduates better support the CINCs through their ability to use and understand new warfare technologies and integrate them into ops plans, campaigns, doctrine and training; orchestrate the tasking of intelligence, surveillance and reconnaissance systems; fully utilize the Global Command and Control System to generate battlespace knowledge; create and execute multi-mission, joint warfare architectures and campaigns; supervise the construction and operation of seamless information networks for use by warfighters; and devise effective combat ID and control measures for joint air defense. Operations Research students are working on ways to improve the Joint Theater Level Simulation (JTLS). Professor Jan Breemer and his colleagues have created a web-based Joint Center for International Security Studies (JCISS), linking national security practitioners in the Pentagon and military services with those in academe. The School has a Center for Joint Services Electronic Warfare Simulation and Modeling, and two programs – Systems Engineering and Integration, and

Information Systems and Operations – are being offered to meet the needs of URL officers. NPS will also be partnering with the Naval War College to offer PME to all Navy students at our command in Monterey.

Designing the Weapons Systems of the Future

If lucky, a surface ship has ten to twenty seconds to defend itself once a guided missile is launched from a nearby shore, or a sea-skimming missile is detected coming over the horizon. Because reaction times are so short, especially with ships now closer to shore missile batteries due to the Navy's focus on littoral missions, the beam from a directed energy weapon travelling at near the speed of light becomes critical for survival, let alone defense.

Future Naval vessels may be able to protect themselves from these and other high-speed threats with powerful Free Electron Lasers (FELs) located deep in the hull, researched by Physics Prof. Bill Colson and over thirty officer students in the Combat Systems/Physics Program at NPS. These futuristic but real weapons will destroy incoming missiles with an intense laser beam travelling out from a ship at near the speed of light, directed out to the target by a one-meter-diameter mirror on the deck. This 100-million-volt electron beam, the power source of the laser, is powerful enough to cut through over a hundred feet of steel in a fraction of a second. The deck mirror also acts as a telescope to give a clear view of target destruction in real time. (Mirrors made of low-density plasmas may also be used to electronically steer shipboard radar in the next century).

"The Free Electron Laser is in the prototype development stage, but we've already demonstrated that lasers can be used to shoot down missiles," said Professor Colson. "These weapons, which are continuously tunable and whose energy can be delivered in short, clean pulses, could be fielded on ships early in the next century. They will bring about a true revolution in military affairs by making missiles obsolete."

Lt. Douglas Small's research, sponsored by SPAWAR's Navy High Energy Laser Office, focused on how to make FELs small enough to fit on board ship, by increasing the laser spot size on the mirrors which bounce the laser beam across the ship and into the sky. The larger the spot, the closer the mirrors can be without being evaporated by the beam. After leaving NPS, he was assigned to the "Surface Combatant in the 21st Century" program at the Naval Surface Warfare Center. For the first time, Lt. Cmdr. Robert Thompson also recently tested the effects of FEL pulses on various target materials.

Due to their power, precision and tunability, FELs may also be used as potent offensive weapons – against enemy aircraft, ballistic missiles, subs, ships, land targets, and even satellites. Whether used offensively or defensively, they must operate in a narrow atmospheric absorption window to ensure the beam is propagated to the target

without losing focus.. Lt. Cmdr. B. K. Baldauf's thesis on shipboard atmospheric profiling and electromagnetic propagation resulted in recommended changes in the Operational Requirements Document for shipboard data collection in this critical area.

NPS student-faculty teams are also working on Directed Energy Warfare (DEW). Lt. Jeffrey Bennett II proved that shipboard radar directed energy weapons can potentially interfere with anti-ship missiles in dynamic flight tests. His thesis, "High Power Radar Effects on Anti-Ship Missiles," was undertaken in cooperation with the USS Cowpens and USS Mahan, and NAWCWPNCEN China Lake. DEW also has applications in information operations (IO). Maj. Bill Lang and Capt. Jay Storms, USMC, for instance, researched using directed energy weapons to jam enemy tactical communications. "It's exciting to be one of the first to receive an education so well suited to meeting the challenges facing the military as it approaches the Millennium," Lang said. The Free Electron Laser and Directed Energy Weapon work are just two research efforts of direct applicability to the Navy's Theater Missile Defense Project.

Computer models and simulations do not yet provide force commanders with an adequate way to evaluate and minimize the threat of anti-ship missiles. Lt. Cmdr. James Townsend developed an optimization tool for this critical function, modeling the entire process by which defending escorts assign defensive fire. With the new system, moving objects are more fully rendered than in current displays – adding smooth acceleration, turning and altitude changes – speeding and facilitating decision-making.

The projectile velocity of traditional propellant guns is limited by barrel weight and length, and their chemical explosives take up critical space. Electromagnetic railguns, which use currents instead of explosives and have no moving parts except the projectile, however, have none of these limitations. At NPS, research is also progressing on these cutting edge weapons with a potential for shipboard use. "Like Captain Kirk and his phaser, the EM railgun lets you 'tune' your voltage, so projectiles can be fired at different velocities and levels of lethality," said Lt. Cmdr. Fred Beach, who developed one of the first prototypes. Another student, Lt. Mike Lockwood, recently demonstrated his next generation version of the gun to German Navy Rear Adm. Detlef Kammoholz.

"This is really a revolutionary advance in fire flexibility and control," Lockwood stressed. "When this technology is perfected, we should be able to launch a mass of 100 pounds up to 200 nautical miles with a muzzle velocity of 6,500 feet per second. For that to happen, however, we will have to solve the power problem. It will require a really huge shipboard power source, on the order of two to four million amps."

In addition to new weapons like the Free Electron Laser and Electromagnetic Railgun, surface ships of the future will continue to rely on guided missiles for both defense and offense. Since the "Father of Cruise Missiles" himself, Rear Adm. Walt Locke (Ret.), graduated from NPS in Electrical Engineering in 1960, student-faculty teams have continued to improve the Tomahawk Land Attack Missile (TLAM), whose program Locke began. This famous NPS graduate later became Director of the overall

Joint (Navy/AirForce) Cruise Missile Project. (See "NPS: A Strategic Investment" Box, p.---).

Today, the Tomahawk missile-to-mission assignment process is still essentially manual, taking up precious time and increasing the likelihood of unnecessary weapons expenditures. When the U.S. struck Iraq in December 1998, an entire battlegroup had to be withdrawn when it ran out of TLAMs, and the replacement ship nearly exhausted her own load by the end of the second day. In response, Operations Research student Lt. Scott Kuykendall developed a robust new computerized tool for optimizing both missile-to-target assignments and firing unit salvo capability for future tasks. Using the program, it takes an individual ship only seconds or a battlegroup only minutes to obtain the optimum tasking order, and also back-up assignments if requested. Kuykendall's tactical decision aid is currently being considered for shipboard implementation by the Naval Surface Warfare Center.

In the early 1990s, Lt. Charles Swicker's thesis on how to use Tomahawks to degrade Iraq's nuclear weapons capabilities, and Lt. Richard Voter's thesis on the intelligence requirements for tracking mobile missiles, became state-of-the-art for intelligence and targeting planners during DESERT STORM. "I was able to recommend both theses to DESERT STORM planners," said Vice Adm. R. M. Eytchison, Vice Director of Strategic Target Planning at Offutt Air Force Base. "Such theses rival the best reports we obtain from contractor think tanks, but at a fraction of the cost. More satisfying is that, instead of civilian Ph.D. contractors, the work done as an NPS thesis makes one of our young officers very well informed on an important topic, and that officer has his whole career ahead of him . . . The Naval Postgraduate School should be pleased that its officers are making noteworthy contributions toward solving current problems while also being educated to lead in the 21st Century."

Professor Donald Brutzman of the Undersea Warfare Academic Group and his students Lts. Martin Whitfield, Chris Hand, Robert Jezek, Jr., and Mark Evans have designed and tested an improved, low-cost torpedo countermeasure using Digital Signal Processor (DSP) technology. The new device, which uses an acoustic modem and all-COTS equipment, will be more effective than current Fleet devices.

Fast, accurate target tracking and Tactical Decision Aids (TDAs) to help decision-makers choose the best response in the limited time available are also important aspects of ship defense. Student Daniel Waddis demonstrated that integrating negative information, that some sensors have not detected a target, into traditional tracking algorithms that normally only use positive target-position data significantly improves overall tracking performance. Lt. Cmdr. N. Wayne Porter applied resource management control (RMC) technology to C4I modeling and simulation applications to develop a TDA to enable shipboard commanders to quickly determine how much time and other critical computational resources it will take to run a deterministic versus a stochastic simulation of a missile's likelihood of surviving anti-missile batteries to reach a target. "This is

extremely important in the crunch of battle," said Porter, "because the shorter time needed to run a deterministic but less informative simulation may be all the time a commanding officer has. Without an RMC decision tool like this, he might still be running his simulation when the missile hits."

Even the best weapons systems are of limited use without fast, accurate signals processing, as well as timely information on the state of the ocean-atmospheric system in the tactical area of operations. Lt. D. Conlee's thesis, "Satellite Image Display and Processing with Microcomputers," is currently being applied by the Fleet Navy Oceanographic Data Distribution System (NODDS). Lt. George Greenway and Computer Science Professor Man-Tak Shing are designing and building a signals collection, direction finding and analysis system using all-COTS components. And a faculty-student team in the Physics Department's Advanced Acoustics Research Laboratory is perfecting Time Reversal Acoustics (TRA) signal processing to significantly improve shallow underwater acoustic communications, of increasing importance with the Navy's post-Cold War emphasis on littoral operations.

"We digitalize the analog signal received by an underwater microphone; time reverse it; and retransmit it from a co-located source," said research director Professor Andres Larraza. "If a wide-aperature array of receivers/transmitters is used, the time-reversed signal back at the point-like source is focused in time and space. Using TRA, the multipath structure is eliminated because all the propagation paths add coherently at the source location, resulting in reduced Inter Symbol Interference of the communication link." "The primary benefit of using the TRA signal processing technique is that it amplifies the desired signal, which improves the signal to noise ratio," added one of his students, Lt. Dave Liddy. "And a wonderful side benefit is that the technique is naturally encrypting. The inherent scrambling caused by the environment at points other than the intended receiver act as a natural barrier." Using computer simulations, Electrical and Computer Engineering international student Antonio Abrantes of the Portuguese Navy recently showed that adding time-reversal focusing with a phase-conjugated array solves the problem of time variability in the receiver channel without the current need for large filters and computational complexity at the receiving end. Another student devised a solution for asynchronous signal processing by adding buffering at the receiving end using special codes.

The environmental intelligence research of Oceanography Professors Roland Garwood, Albert Semtner, Robin Tokmakian and others focuses on predictive, visualizable ocean modeling from the global down to the littoral and turbulence scales. According to Garwood, by 2020 – the year of our scenario – global ocean forecasts, integrated with worldwide atmospheric prediction models and updated with near-real-time remote/satellite and in-situ data, will be able to predict and visualize surface ocean currents up to *two weeks* into the future. Already, sea-monitoring satellites, like QuikScat, are able to collect data in a 1,000+-mile swath, covering 90 percent of the Earth's surface

daily. Obvious applications include optimal ship routing and tactical mission support. Of particular relevance to surface ships is the thesis of Lt. Cmdr. Brian Connon, who married a MORIAH-like shipboard environmental sensor suite and METCAST meteorological data and information product distribution system via the Automated Digital Network System (ADNS) to provide small ships with the first ever constantly updatable METOC intelligence capability. NPS also specializes in littoral acoustics research, through its Ocean Acoustic Observatory, Innovative Coastal-Ocean Observing Network, Synoptic Analysis and Forecasting Laboratory, and Interactive Digital Environmental Analysis (IDEA) Laboratory, among others. "The Ocean Acoustic Observatory is a national treasure – like a 'Hubble Telescope' of the seas – that could only have been achieved by the Naval Postgraduate School," said facility manager Chris Miller.

Advanced research on atmospheric intelligence is supported by six laboratories serving the Department of Meteorology – the Interactive Digital Environmental Analysis (IDEA) Lab, Remote Sensing Lab, Numerical Modeling Lab, Synoptic/Mesoscale Analysis and Forecasting Lab, Tropical and Monsoon Lab, and Marine Atmospheric Boundary Layer Lab.

The NPS Center for Reconnaissance, directed by Electrical Engineering Professor John Powers, focuses on the naval applications of optical devices, fiber optics and fiber lasers, acousto-optics, scalar-wave diffraction, acoustic imaging, optical and image signal processing, electronic warfare, and weapons systems analysis. The School also has Joint C4I and Intel Information Management curricula; a Signal Intelligence Center and a Signal Enhancement Laboratory to improve antenna performance and the signal-to-noise ratio at radio receiving sites; a unique radar laboratory with over 15 different instrumented radar systems; an advanced C4ISR Systems Technology Laboratory with near-real-time access to a Global Command and Control suite and the Joint Defense Intelligence Support System (JDIS); and two Sensitive Compartmented Information level laboratories.

NPS also has a number of research programs devoted to detecting, identifying, classifying, and defending ships against sea mines, an effort which has become more critical given the Navy's post-Cold War emphasis on littoral operations. Operations Research Professor Alan Washburn has developed a minefield clearance model and tactical decision aid for determining the optimal search method for specific mine clearance operations. The thesis of Lt. David Romberger, one of his students, on this subject was distributed to the entire mine warfare community by the Naval Coastal Systems Center, in 1997. Lt. Sean Fitzpatrick and Maj. Patrick Hall, USMC, researched the problem of detecting mines buried in surf zone sediments and beaches under the direction of the current Chair of Mine Warfare, Professor Thomas Muir. As noted earlier, the School has an ongoing advanced research program on remotely controlled, autonomous and semi-autonomous underwater vehicles, which can be used for mine hunting. And NPS co-sponsors and hosts a major international conference on "Technology and the Mine

Problem," pioneered by former Mine Warfare Chair, Professor Albert Bottoms, which addresses both sea and land mines, every year and a half.

The best way to defend a vessel is for it not to be detected in the first place. Three important and related forms of ship defense are therefore electromagnetic signature reduction, signature management, and designing new ships from the keel up with built-in stealth characteristics. NPS has ongoing research in all three areas. In the future, based on faculty-student research, highly visible antennae -- key ship identifiers to a hostile force -- will be minimized or even eliminated through phased array antennas built into the hull and superstructure of the ship. Infrared detectors, used heavily in night operations, hone in on heat; NPS therefore has an active research effort devoted to ship infrared signature reduction. Professor Knox Millsaps is working on stack cooling. Professor Thomas Hofler and his students are perfecting an innovative way to remove all tell-tale waste heat from a ship's electrical and power systems and turn it into refrigeration to meet all shipboard cooling needs using high-intensity sound waves. Such thermoacoustic refrigeration is simple and inexpensive, has no moving parts, and is entirely environmentally friendly, producing no chlorofluorocarbons or toxic chemicals.

Designing Future IT Defense Systems

The Revolution in Military Affairs is being driven by exponential increases in the speed and power of computations and communications, and the coupled decrease in reaction times. A *thousand*-fold increase in computational power is expected between now and the year of our scenario, 2020. In the future, the continued advance of miniaturization and cross-platform networking to implement Cooperative Engagement Capability fleetwide will also make computers even more ubiquitous than they are today, woven into the very fabric of ship and crew. This explosion in the number and variety of computational devices, however, introduces enormous vulnerabilities to hacking, viruses and other information system attacks unless security considerations, as well as function and performance, become central to information system design, implementation and management.

NPS anticipated this threat long ago, becoming the world's academic/research leader in the fields of Information Security and Information Warfare. It has curricula in Information Warfare, Electronic Warfare, Information Technology Management, and Joint C4I Systems, among others, and a Secure Computing Network Research Laboratory. In 1996, it opened the nation's first Center for Information System Security Studies and Research (CISR), which is on the vanguard of INFOSEC education and research, producing officers who understand the complex realities of computer security.

Because malicious software attacks may be undetectable when instigated by a technically expert adversary, self-protecting security mechanisms are necessary to protect critical shipboard applications and data. Computer Science Professor and director of

CISR, Cynthia Irvine, is working on a high assurance security infrastructure that will ensure self-protecting enforcement of critical security policies in a cleared-user-friendly environment. Capt. Katrina Hensley, USMC, and Capt. Fredrick Ludden, USA, are working with Computer Science Professor Geoff Xie on enhancing the ability of high-speed nodes to discard bogus traffic without significant loss of performance. Computer Science Professor Dennis Volpano is designing computer languages that would prohibit secrecy- or integrity-policy violations. Lt. Anthony Hansen and Captains Dan Morris and David Rowe, USMC, are working with Professors Irvine and Michael on emerging public key infrastructure issues impacting Internet and Intranet authentication. Lt. Lee Joyner has developed a new high performance firewall architecture, and Lt. Susan Byer-Joyner and Lt. Scott Heller created high assurance server software to authenticate and multiplex clients at different secrecy levels.

NPS is the only institution of higher education to offer a course of graduate studies in Information Warfare, and also has an Information Warfare Academic Group. To keep the Group at the cutting edge of the most current military thinking in the field, a Chair of Information Warfare was established, with its first incumbent, Capt. James R. Powell, coming directly from the staff of the Joint Chiefs of Staff. In Fall 1997, the first eleven Navy officers and Army officer ever to receive a Master of Science in Systems Engineering with a specialty in Information Warfare -- a new interdisciplinary academic program sponsored by the Joint Staff (J39) and the Commander, Naval Security Group that qualifies its graduates as Information Warfare Subspecialists – graduated from NPS. Since then, Powell and Computer and Information Sciences and Operations Division Dean Dan Boger have taken major steps to ensure full participation by all the services. Beginning with Fall quarter 1999, the School will also offer a new curriculum in Information Systems and Operations designed to meet the needs of unrestricted line officers in this field.

The Navy is the only service whose operations cover the whole range of military systems – surface, sub-surface, air, space, and ground. In addition to being secure, therefore, future Navy IT systems will also have to be interoperable across a wide variety of platforms. And as ships' operational tactics and plans evolve, so must their supporting IT architectures.

Electrical and Computer Engineering Professor Vicente Garcia, the National Security Agency (NSA) Visiting Chair for Cryptology at NPS, and a team of students are reviewing and evaluating current Ship Signal Exploitation Spaces (SSESs) with the goal of establishing a vision and guidelines for the shipboard cryptologic architecture of the future. Garcia, along with Capt. Powell, mentor students in leading edge research in Information Warfare/Information Operations (IW/IO), including IO modeling and simulation, directed energy warfare, electronic warfare, defensive IO/Information Assurance, and automated intelligence. Classified laboratories, including the Cryptologic Research Center Lab where innovative IW/IO solutions are developed, support this work.

The School also has a Center for Joint Services Electronic Warfare Simulation and Modeling, and a newly upgraded Secure Computer Processing Laboratory.

Just-in-Time, Onboard 'Virtual Reality' Training

The 2020 surface ship, like the one in our opening scenario, will have extensive onboard 3D 'Virtual Reality' simulation capability, in response to DoD's demand for realistic, effective, low-cost training options. These Virtual Environments (VEs) allow personnel to 'advance-view' operational and battlespaces and act out scenarios in those 'spaces' without having to enter actual dangerous terrain. VEs will be able to robustly simulate the visual, auditory, and even tactile aspects of ship, sea, aircraft, air and land environments, and extensively incorporate user-movement feedback. Users will interact with these Virtual Environments by means of special gloves, helmets and holographic heads up displays – like the one in our scenario.

Under the leadership of Professors Michael Zyda, Rudy Darken and John Falby, the NPSNET Research Group's Virtual Reality Lab has become a world leader in developing large-scale Virtual Environments for ship, sub and helicopter handling and damage control training using many of the above noted capabilities, including the Omni-directional treadmill used by Marines in our scenario to 'insert' themselves into the virtual landscape. In 1996, NPS stood up a new Modeling, Virtual Environments and Simulation (MOVES) curriculum offering an M.S. degree, with a Ph.D. program now under development. Its students learn how to combine computer science, operations analysis, mathematics, and human-computer interaction research to produce complex, large-scale VEs. There is now also a MOVES Academic Group.

Current MOVES thesis work includes research on constructing Virtual 3D Environments, like the one in our scenario; VE networking; web-based interoperability; inertial motion tracking; integrating spatial sound; VE navigating and wayfinding; and the creation of cross-platform VE toolkits. Students use the Defense Modeling and Simulations Office's High Level Architecture for network communications.

Capt.. Tim McLean, USMC, developed a self-contained helicopter pilot training simulator usable by any Navy facility worldwide. Lt. Steve Norris is developing a shipbuilding task model for Surface Warfare Officer School, Newport, Rhode Island, and a number of real-time surface ship simulators have also been developed. Maj. David Kirzov, USMC, designed an integrated data and display system for Tactical Training After Action Reviews (AARs). Professors Ted Lewis and Dennis Volpano are on the forefront of using wireless communications to obtain near-instantaneous field updates.

Computer simulations don't just model the future. They can also be used to 'see' the past. One NPS student, Capt. John America (USMC) -- his real name -- used

advanced computerized wargaming to 're-play' key battles and decide which version of written history is more accurate.

"Training is the future of combat modeling," said America. "With it, we can learn by making 'virtual' mistakes, instead of losing *real* lives."

As preparation for actual operations, virtual environments are useless unless their simulations correspond to the real world. Ensuring such high level 'reality fidelity' will require extensive use of remote sensing, via satellites and autonomous and semiautonomous vehicles.

Leading-Edge Research on Unmanned and Optionally-Manned Vehicles

Simulation training is practice for actual manned missions. Some missions, however, are too dangerous, dirty or dull to risk valuable human resources. The answer is unmanned vehicles, which were part of our scenario and are revolutionizing the way the military conducts its operations. NPS faculty-student teams are leading the way in this cutting edge field, developing autonomous and semi-autonomous air, land and sea vehicles for remote-surveillancce; target tracking and identification; electronic warfare; neutralization operations; and many other critical missions.

The School has a new Center for Interdisciplinary Remotely Piloted Studies (CIRPAS), a first-of-its-kind facility providing UAV flight services to the research, development and test-and-evaluation communities, initially formed with the support of the Office of Naval Research. The Center has a medium-altitude "Predator" UAV from the Tactical Control Station Program, the first of two; a long-duration remote measurement "Pelican" Optionally-Piloted Aircraft, also the first of two, one of which has been upgraded to "Predator" flight control capability; and the high-altitude, long-endurance (up to 35-hour mission) "Altus." All can be operated via satellite links by a "pilot," "co-pilot" and engineering flight technician who make adjustments from a ground "cockpit" just as if they were actually in the aircraft. The unmanned and optionally-manned aircraft can be used for a wide variety of missions, including meteorological, biological and chemical testing, and reconnaissance. And, unlike satellites, they can be instantly and freely maneuvered to cover targets. Students are now automating the process by which digital UAV data -- optical and infrared images, target track kinematics, and other telemetry – is down-linked and converted into Global Command and Control System (GCCS) or Joint Maritime Command Information System (JMCIS) target tracks for use by warfighters. CIRPAS recently joined forces with the Naval Research Laboratory to advance the development and use of UAVs in Fleet operations and exercises.

UAVs are also a major focus of the NPS Information Warfare Academic Group, led by Capt. James Powell. He and his students are marrying the EA-6B with distributed UAVs and Uninhabited Combat Air Vehicles (UCAVs) to advance Navy Tactical Air Electronic Warfare (TACAIR EW). Operations Research student Lt. Tim Barkdahl is

applying modeling and simulation to this topic, and two classified projects have been completed on UAV EA payloads. Prof. Russ Duren of Aeronautics and Astronautics is developing an avionics system definition for networked UCAVs in close air support missions, as well as a small autonomous helicopter. Two Operations Research professors, Donald Gaver and Patricia Jacobs, are assessing the value of particular UAV forces embedded in a total C4ISR system. Operations Research Professor Alan Washburn has developed a visual simulation of vertical takeoff and landing UAVs in target ID missions. Students use Prof. Isaac Kaminer's Rapid Prototyping System (RPS) to design, simulate, implement and flight test experimental avionics software packages, and even make and evaluate code changes during the tests. Kaminer is also researching the multi-sensor fusion and algorithmic requirements needed to robustly auto-land UAVs on board surface ships using only passive sensors.

NPS is also a leader in developing inexpensive, expendable Miniature Air Vehicles (MAVs) for indoor and outdoor hazardous area surveillance, like the ones deployed to the island in our scenario. The first battery-less, fuel-less prototype is only 2 inches wide and 4-1/2 inches long, with a 5-inch rotor. Designed by Professor David Jenn and his civilian student Robert Vitale, the mini-craft is powered by 1-1.3-GHz/1.8-Watt microwave radiation 'beamed' to its whole-body 'antenna' and converted into a DC signal, which powers a tiny motor for propulsion. Future MAVs, which can also be powered by shipboard radar like the SPY-1, will carry an array of sensors, including tiny video cameras and chemical and radiation detectors.

"Our prototype is the first known use of a radar signal to operate a micro air vehicle," said Vitale. "At the (low) power levels we use, our electrical motor also operates at the greatest known distance from a microwave antenna. By the year of your scenario, 2020, if funded, micro UAVs could be operable by radar at up to one mile from a larger air and/or ground vehicle, or at longer ranges from satellites beaming from orbit. Wireless power transfer will also be used for at-a-distance automatic personnel and equipment identification, using radio-controlled bar-code (RFID) tags."

Professor Anthony Healy and his team at the NPS Center for Autonomous Underwater Vehicle Research have been developing autonomous underwater vehicles (AUVs) that can operate in depths of up to 300 feet for remote surveillance, mine detection and neutralization, and other missions. Their "Phoenix" AUV, designed to detect sea mines, was recently tested successfully in a littoral saltwater environment. It uses GPS for surface navigation, and numerous sensors when submerged, including an acoustic short baseline system with Doppler sonar, a three-axis magnetometer, six-axis inertial sensor, three angular rate gyroscopes, and three accelerometers. Professor Rick Howard and his students are evaluating maritime UAV designs, including vertical takeoff and landing models, for viability and robustness.

For land missions, a number of faculty-students teams are developing remotely-controlled, semi-autonomous and autonomous robots for hazardous area and terrain

surveillance, and researching the best control and search algorithms for different missions. Computer Science Professors Wolfgang Baer and Neil Rowe have pioneered the near-real-time updating of virtual models using 'ground truth' data from various remote sensors.

Inventing the Ship Defense and Damage Control Systems of the Future

With the Navy's emphasis on ship self-defense, automated ship damage control systems will become increasingly important as response times to future high-speed weapons become shorter and shorter. The computer in our scenario provided synthesized voice read outs from such an Integrated Digital Ship Control System.

Systems Management student Lt. Frank Steinbach has developed an evolutionary computer model to enable planners to choose the best commercial-off-the-shelf IT package to upgrade damage control communications on aircraft carriers. Based on his research, the current manpower-intensive system of sound-powered phones, grease pencils and human runners will be replaced by the best possible system of wireless Local Area Networks, barcode readers, flat and touch screen displays, handheld computing devices, avatars, and tactical decision aids. Steinbach's thesis advisor, Professor Luqi, chairs the NPS Software Engineering Program, one of whose distance learning courses the officer student in our scenario was taking on board ship. The captain of that future scenario, Chris Williamson, is now a Navy lieutenant getting his Masters and Ph.D. degrees in that same program. He is applying the principles and practices he learns in class to develop a knowledge-based expert system synthesizing helicopter pilot flight record data and after-action review reports.

Lt. Phillip Beachy developed a Tactical Decision Aid which calculates the probability that a submarine will penetrate a carrier or other high-value asset's inner-zone ASW screen, maintained by helicopters using active dipping sonar. The TDA was designed for use by planners attempting to design better ASW screens. Operations Research student Lt. Jack Thomas has written a computer program to help the Navy make the best choice from among competing Hyperspectral Imaging (HIS) passive optical sensors, which can detect subs and seamines using only the light of the sun -- particularly important given the Navy's new emphasis on near-shore areas where quiet diesel-electric subs can lurk in murky waters. Lt. Cmdr. Daphne Kapolka's Ph.D. research focused on how to make subs quieter by measuring and masking the noise from their engines and onboard equipment. And Physics Professor Thomas Hofler and his colleagues have invented a new velocity-sensitive, as opposed to pressure-sensitive, hydrophone, hundreds of which may coat the front of future submarine hulls to passively detect underwater craft.

Designing new ships for maximum survivability is a focus of NPS' Total Ship Systems Engineering team. Its head, Professor Charles Calvano, predicts future ships will have automated compartment, equipment and hull monitoring, and even a 'flinch' system that predicts the likely location a missed missile is about to hit and automatically turns on

sprinklers and closes doors, hatches and valves, etc. in *anticipation* of a hit. Professor Knox Millsaps and his students are working on automated sensor-based monitoring and condition-based preventive maintenance of onboard equipment. According to Calvano, logistics commands in the future will be able to remotely monitor onboard equipment, compartments and hull via such sensors and arrange for replacement parts to be flown out to or be ready for a ship when it comes into port. Professor David Schrady has developed a computerized tactical logistics support system, TACLOGS, to plan, track, and predict the use and just-in-time replenishment of fuel and ordnance by individual ships within battlegroups, significantly increasing sustainability at sea. Operations Research student Lt. Mark Thornell created a tank and void database to track servicing and establish maintenance priorities for these large systems. One of Calvano's students, Lt. Luis Ordonez of the Colombian Navy, analyzed a trimaran-hull-form ship, like the one in our future scenario, for damage stability under differing conditions. An artist's rendition of this tumblehome-hull-form craft is on pg. ---. These vessels, designed to better withstand hits from sea-skimming missiles and torpedoes, are being evaluated at NPS under a joint U.S. Navy-Royal Navy program..

And, unfortunately, not all shipboard casualties are the result of enemy actions. "Friendly fire" casualties also need to be defended against and, once again, our students have taken the lead in addressing this problem. The situational awareness beacon scheduled to be deployed on every surface ship by the year 2001, SABER, was developed by a series of students' proof of concept research at NPS. And Capt. Mark Grabski, USA, assessed the effectiveness of the Battlefield Combat Identification System (BCIS), used to improve target identification and situational awareness for ground combat troops, also to mitigate direct fire fratricide.

Securing Future Navy Assets in the Ocean-Space Continuum

Space is the ultimate high ground *and* an 'ocean,' which we travel in space*ships*. Given the imperative of holding this high ground if we are to remain the sole superpower, the U.S. military has moved more and more of its assets into the ocean-space continuum. The future will see an even greater use of this ocean-space continuum by the Navy for communications, reconnaissance, real-time targeting and weapons control, direct-to-battlefield down links, remote control of land- and ship-based autonomous and semi-autonomous vehicles, and many other missions. Then as now, spacebourne military communications hardware will require high-speed circuitry able to operate under conditions of high radiation exposure. Ship-based and space-based data processing and communications systems will soon need to support data rates of one hundred gigabits per second and higher, which are achievable only through the use of non-silicon-based semiconductor technologies such as gallium arsenide (GaAs) and indium phosphide (InP). These exotic technologies will only become practical, however, if their high energy

requirements and vulnerability to space-radiation-induced errors can be dramatically reduced.

Electrical and Computer Engineering/Space Systems Academic Group professors Todd Weatherford and Douglas Fouts and their students are solving these problems critical to securing the Navy's future assets and operations in, from and to space. They have demonstrated that including a buried layer of beryllium-doped, low-temperature grown GaAs under transistors in GaAs substrates can reduce the radiation-induced single-event error rate in GaAs integrated circuits by *up to 100 million* times; and that using dynamic logic circuits can reduce power consumption by *up to 50 percent*. One of their students, Michael Warren Schimpf, recently designed, tested and evaluated GaAs PN sequence generator circuits. Another, Maj. James Devers, did his thesis research on the dependence of single event upsets in GaAs transistors on radiation frequency. Yet other students are using NPS' linear accelerator to study the damage effects of radiation on transistors. In this, they were foreshadowed by one of NPS' most noted graduates, Rear Adm. Wal Locke (Ret.) -- "The Father of Cruise Missiles" -- who did his 1960 thesis in Electrical Engineering on the effects of gamma rays on circuit transistors. Then, as now, space-based military communications hardware demands high-speed circuitry hardened against the effects of radiation.

The Naval Postgraduate School also made history with the recent Shuttle that returned former astronaut and Senator John Glenn to space. That mission launched the School's Petite Amateur Navy Satellite (PANSAT), a small proof-of-concept satellite for low-cost store-and-forward digital communications using direct sequence spread spectrum in the Amateur Radio UHF frequency band and a flexible architecture that allows experimental software modules to be uploaded while in orbit. The project is the embodiment of over fifty student theses under the direction of principal investigator, Dean of Science and Engineering, and Chair of the Space Systems Academic Group, Professor Rudy Panholzer; Project Lead Associate Professor I. M. Ross; and Project Manager and Systems Engineer Dan Sakoda. PANSAT is expected to be in orbit for at least four years, during which time it provides a unique, hands-on space-based laboratory for additional officer students in Space Systems Engineering and Space Systems Operations to experiment with satellite communications, attitude and orbital dynamics, thermal analysis and even the uploading of experimental software modules. Students will also handle all spacecraft operations and control throughout the life of the spacecraft. The satellite's potential military applications include assisting with downed pilot rescue operations and logistics traffic, and over-the-horizon communications.

"I like to see ideas come to fruition," said Lt. Steve Bible, one of the fifty whose thesis research contributed to the project's success. "The PANSAT project provided me the unique ability to think a problem through and implement the idea. Now to see PANSAT fly gives me a sense of satisfaction unparalleled in any other project."

Other projects of Space Systems Academic Group faculty and students include contributions and improvements to the International Space Station, design of Mars mission orbits, and work on a whole-earth planetary defense system to protect humanity from extinctor-size asteroids and comets -- the 'real thing' only hinted at in the movies "Deep Impact" and "Armageddon."

The School has curricula in Space Systems Operations and Space Systems Engineering. It also boasts a Spacecraft Research and Design Center, a Research Center for Military Applications of Space, a Fleet Satellite Communication Laboratory, a Spacecraft Integration and Test Laboratory, a Spacecraft Attitude Dynamics and Control Laboratory, a Spacecraft Environmental Simulation and Test Laboratory, and a Secure Space Systems Research Laboratory. NPS also has a number of research projects focused on improving and utilizing the Global Positioning System (GPS).

While most NPS graduates are still assigned to sea missions, so many are venturing into the "Final Frontier" that NPS is among the top four schools in producing future astronauts. Since moving to Monterey from the Naval Academy in 1951, NPS has already graduated 35 astronauts, some 20 of whom have flown Space Shuttle missions. Three dozen Shuttle missions included former NPS students, who have launched dozens of communication satellites; conducted physics and medical experiments in zero gravity; and helped build the International Space Station. Three graduates flew Apollo moon missions, with alumnus Capt. Eugene Cernan the last man to walk on the moon; and three served aboard America's first experimental space station, Skylab. Of the 210 Navy selectees for NASA's Space Shuttle Astronaut Program announced this April, nearly half -- 98 -- were NPS graduates. Of the 210, fewer than 30 will make the final cut in any Astronaut Candidate Class. Last year, five of the eight Naval and Marine aviators selected for the 1998 Astronaut Candidate Class were NPS graduates. Many of these future and past astronauts did their thesis work under the NPS Space Systems Academic Group, which also launched PANSAT.

"NPS was essential to my becoming an astronaut," said Capt. Winston Scott, a former Aeronautical Engineering student who has completed numerous Shuttle missions constructing the International Space Station. "Without the education I received here, I wouldn't have been prepared for what I do now. I could not have become an astronaut without it."

In 1986, the relationship between the Naval Postgraduate School and NASA Ames Research Center (ARC) was strengthened and formalized through the formation of the Navy-NASA Joint Institute of Aeronautics, dedicated to inventing and improving future aero and space technologies, under the direction of Distinguished Professor Max Platzer. The Institute fosters communication between NPS, other DoD agencies and ARC; makes NASA's expertise and research and test facilities available to faculty and students; facilitates bilateral exchanges through courses and seminars; and identifies and creates thesis opportunities for students and research openings for post-doctoral fellows and

visiting research scientists, at the NASA facility. NASA Ames' most recent list of its own major accomplishments, in a report to the Office of Aero-Space Technology, includes research by NPS Aeronautical Engineering student Lt. Pete Tyson on rotor design options; with four of eight listed "Technical Highlights" also contributions by NPS officer students.

The Future Naval Postgraduate School:
Leading the Revolution in Military Education

By the year of our scenario, 2020, the Naval Postgraduate School will have long been a hybrid In-Residence/Virtual University. We are already headed in this direction. In Spring 1999, NPS faculty taught video-teleconferenced courses to a total of 165 non-resident students at eight Distance Learning sites. 123 of these were enrolled in degree programs and 42 in individual classes. And this Spring 2000, the first nine Nuclear Reactors engineers students received NPS masters degrees in Engineering Science through the School's latest Distance Learning joint program with the Naval Reactors' Bettis Reactor Engineering School (BRES).

But we will never get to our Vision of becoming *the* technologically integrated Defense University and Virtual University services provider of the future until we are able to pipe each one of our 46 defense-vital graduate education programs into Shipboard Learning Centers on every ship in the Fleet.

This was brought home to me recently when I had the opportunity and honor of meeting with dozens of pioneering Ph.D. students in our first-ever Ph.D. program *and* first-ever distance learning program in Software Engineering anywhere in the world. Their testimonials, delivered during their few days on campus out of the whole year to take their exams, made me realize how important – and *achievable* – this Vision is.

Perhaps the most moving testimonial was from a young Navy lieutenant and helicopter pilot who has been taking video-teleconferenced Masters and Ph.D. classes in Computer Science/Software Engineering while underway on operational duty – Lt. Chris Williamson. He reminded me of another young lieutenant and helicopter pilot who, not too long ago, got his degree in Computer Systems Management at NPS. That student was myself. The only difference between us -- besides a few years -- is that I did it here, in residence on campus, and he is doing it while deployed-underway.

"This program has been a great benefit to me and to the Navy," Williamson said in that meeting with dozens of other distance learning students in the Admiral's conference room earlier this year. "I'm able to expand myself – to get my masters and Ph.D.-- while maintaining an operational commitment, and the Navy still gets the operational gain by filling the billet, but at a dramatically reduced cost because I'm doing it through distance learning. The classes never conflict with my work schedule. The only modification I had to make was to come in one hour earlier in the morning so I can leave an hour early at the

end of the day. My commander understands that, and sees the benefit of it. I was able to keep up with classes while on cruises – two-week, six-week cruises, even during RIMPAC – through video-teleconferencing and videotapes, and got all of my class notes via e-mail. This (the year-end exam) is the first time I've been on campus and, theoretically, I wouldn't have come here again until graduation. And that's ideal, because we're understaffed and need our people to maintain their operational commitments. But they need to know they can still do that *and* advance their educations, while serving the Navy. The TAGs and the CINCs and the TYCOMs are all interested in this program, and want to know what we can do to expand it immediately. They also ask why I'm the only uniformed service member in the program."

"As a Navy officer, you learn to flex. You learn that's just the way you do business. Now it's the Navy's turn to 'flex.' It's *so* important we get this to as many people out in the Fleet as we can. We should be openly recruiting deployed Naval officers to join the NPS Distance Learning Program, and encourage a change in the traditional assignment of officers to NPS to be able to fulfill that in alternative options like the DL-VTC program. From the top down, the Navy needs to endorse a change in policy and practice to officially recognize the NPS Distance Learning Program as a viable option to traditional education."

I couldn't have said it better myself. Now it's our turn to 'flex,' and I intend to do just that. If Lt. Williamson can do it, we can all do it. I am committed to doing whatever it takes while Superintendent of this great institution, and after, to see that Lt. Williamson's vision becomes a reality. Because it's the CNO's Vision. In his message to commanding officers in July, Admiral Johnson placed new emphasis and funding priority on developing distributive learning opportunities for graduate education and PME throughout the Fleet. And because it's *my* Vision. After all, that's why I made Lt. Chris Williamson the Captain in my scenario.

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