V-22 OSPREY:

WONDER WEAPON OR WIDOW MAKER?

They warned us. But no one is listening.

BY LEE GAILLARD

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For the MV-22 Osprey—sunrise or sunset?

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"I think the V-22 is not a good aircraft for combat."

—Anonymous Marine participant in V-22 testing

About the Author

Lee Gaillard has written more than 100 articles and book reviews (many of them on defense issues and aviation), which have appeared in *Defense News*, *The Seattle Times, Technology Review, San Diego Union-Tribune, Air & Space/Smithsonian, Proceedings, Marine Corps Times, The Washington Times, Submarine Review, Armed Forces Journal International*, as well as other magazines and newspapers around the country.

Gaillard holds a bachelor's degree from Yale University and a master's degree from Middlebury College, specializing in English and American literature. Following his university studies, he spent time in the Marine Corps Reserve and in publishing (at *Time-Life International* in New York). In addition, Gaillard has worked for a French airline, worked in education in Greece and the United States (including many years in school administration in the United States), worked as a senior product marketing specialist for the world's largest manufacturer of semiconductor assembly equipment, and, over the last 20 years, has researched and published numerous freelance articles on defense issues and aviation.

In 2002, Gaillard attended the Royal Institute of International Affairs defense conference in London, U.K.: "Europe and America: A New Strategic Partnership," and subsequently wrote two related articles that appeared in *Defense News*. After *Airways Magazine* (July 2005) published his examination of the National Transportation Safety Board's flawed investigation of the American Airlines Flight 587 disaster, he served on a panel of analysts assembled for "Airline Cracks," a documentary on load-bearing composite structures in commercial jetliners, telecast by ITV-West (Bristol, U.K.) on Oct. 4, 2005.

Gaillard is listed in *Who's Who in America* (2002, 2003, 2004 editions). His affiliations include (among others) the U.S. Naval Institute, the Federation of American Scientists, Nature Conservancy, and the Natural Resources Defense Council. He is a contributor to the Center for Defense Information's Straus Military Reform Project.

EXECUTIVE SUMMARY

Faster than the fastest helicopter, able to leap vertically to lift troops and supplies to inaccessible locations behind enemy lines, the *Osprey* epitomizes a transformational super-craft able to swoop, raptor-like, onto an enemy with deadly results. But throughout the V-22's development, 30 people have died—and now this glitch-plagued program that survived one cancellation and numerous design and operating problems is poised to reveal fundamental flaws that may cost even more lives.

The U.S. Air Force wants 50 CV-22s for special operations; the Navy wants 48 for rescue of downed pilots and other missions; the Marine Corps wants 360 MV-22s to replace aging CH-46s and CH-53s to airlift troops and supplies from beyond the horizon directly to inland positions, bypassing vulnerable beachheads.

If deployed in combat, the price could be fatalities inflicted not just by enemy fire, but by flaws that were the result of omitted tests and basic design deficiencies pointed out but never addressed. The question will become, "Who should be held accountable?"

Tipping Point: The Pentagon's September 2005 Report

Following completion of its operational (combat "realistic") testing, the Pentagon concluded in September 2005 that "the MV-22 Block A is operationally suitable" and is "compatible with flight and hangardeck operations." Full production would follow. *Yet evidence within the report itself and in ongoing flight operations shows that in the 17 years since its first flight, the V-22 does not work and faces operational, aerodynamic, and survivability challenges that will prove insurmountable, and lethal, in combat.* Largely following the format of the Pentagon's V-22 evaluation, this analysis examines the *Osprey*'s protracted development, aerodynamic challenges that were not resolved and warnings that have been ignored.

Wars Missed

The *Osprey*'s combat début is set for Iraq in 2007. But the V-22's protracted development has spanned a quarter-century and already caused it to miss deployment to Bosnia in 1995, Afghanistan in 2001, and Iraq in 2003—despite a first flight on March 19, 1989.

A New Technology and Four Crashes

The unique V-22 is an exemplar of multinational endeavors reaching back more than 50 years. But this paradigm shift to an assault transport combining capabilities of both helicopters and aircraft involves a problematic transition from flexible low-twist helicopter rotors to stiffer, high-twist, high rpm, tilt-props. Thus the V-22 enters an unexplored realm fraught with aerodynamic unknowns.

Four crashes ensued—in 1991, 1992, and two in 2000—with 30 fatalities. Three were triggered by below-standard parts, software and/or abysmal assembly line quality control; the fourth was caused by a dangerous aerodynamic phenomenon—vortex ring state (VRS). VRS occurs when a rotor becomes enmeshed in its own downwash and loses lift—with thrust from the remaining rotor often rolling the aircraft into an uncontrollable, inverted dive. Rapid descent vertically or at low forward speed creates conditions ripe for VRS.

Combat deployment in 2007: is the V-22 ready?

VRS and blade stall comprise the most dangerous and complex issues facing the program. VRS can be deadly and is intensified by the blade stall (and loss of lift) triggered during descent when the V-22's extremely high-twist rotorprops cause the smooth laminar flow across the blades' upper surfaces to be replaced by boundary layer separation and turbulent flow. This is the primary reason why the maximum vertical descent speed of 800 feet per minute (fpm)—that's just 9.1 mph—is mandated for this aircraft. It is so slow it will make the V-22 an easy target. This performance limitation is lethal to the aircraft as well as its crew and human cargo. Equally bad, combat pilots trying to insert troops urgently into a "hot" landing zone, where the enemy is shooting, may try to descend more quickly, thus encountering VRS, which will likely roll the aircraft into an inverted dive toward the ground and lose everyone on board in the process. So should a pilot choose to descend at 9.1 mph? If he does, he'll get shot out of the sky. Should the pilot go in fast instead? If he does, a crash is imminent. It's a Catch-22. This design anomaly has not been, and probably cannot be, eliminated.

Now add in faulty flight control software that tries to counter pilot commands, alternately increasing and decreasing power to aircraft rotors. At a March 2006 event, a V-22 inadvertently took off by itself, falling back to the ground and snapping off a wing, demonstrating the frailty of the system.

Add also severe downwash, which knocked over two Marines in one incident and in another caused the pilot to lose visual contact with the water surface so that the aircraft's belly plunged into the waves.

Add the missing defensive gun and personnel hoist, ongoing failures of other parts, and small, poorly placed cabin windows preventing crew chiefs from scanning for threats—and the potential for mishaps and lost lives becomes virtually inescapable.

Consider other survivability-related omissions, such as the failure to test the aircraft against rocket-propelled grenades (RPGs) used so frequently by insurgents in Iraq.

Finally, consider the flight manual instructions to pilots to convert to "airplane mode or autorotation" in case of dual engine failure, even though the DOD report says "the V-22 cannot autorotate to a safe landing."

Altogether, it is an aircraft waiting to increase its casualty list single-handedly if it is ever permitted to go to a combat theater.

Quality control and the *Osprey* money machine

Production facilities of V-22 co-manufacturers Bell-Textron and Boeing achieved prestigious International Standards Organization (ISO) benchmarking certification. Yet during testing preceding the fatal December 2000 crash, the V-22's hydraulic power system suffered 170 failures. Flights were suspended; after they resumed, propeller parts sheared off, and in March 2006, that idling V-22 took off by itself—slamming back to the ground.

Thus, we can quickly see how the *Osprey* might transmute into a Phoenix, an Albatross, or a goose laying golden eggs. It had a rebirth after program cancellation; but weighing in at $70 million a copy, it is a drain on taxpayers. It feeds the military-industrial-congressional feedback loop of campaign donations, production orders, and jobs created in 276 different congressional districts. So many billions of dollars have been spent that the program's momentum precluded shutdown—despite serious ongoing problems.

Testing was inadequate

Specific tests to investigate methods of operating safely within VRS, widely recognized as a potential problem, were cancelled, and because of danger to the rotor system and crew, test aircraft transitioning to helicopter mode "did not employ rapid tight turns" that a helicopter would have used for evasion.

V-22s can supposedly make vertical takeoffs or landings with one engine inoperable, *yet during 17 years of testing, this maneuver has never been attempted.*

Of 29 night mission profiles, only 12 were accomplished.

Intended testing under severe brownout conditions caused by violent V-22 downwash did not occur.

V-22 operating goals not met

The Pentagon considers the MV-22A "operationally effective," yet the range of the improved model will fall 42 percent short with a 10,000-pound external load.

The computerized mission planning system is inadequate.

The V-22 cannot carry an up-armored Humvee (HMMWV).

A time of reckoning

Key Pentagon leaders read in early 2001 how operational test planners had "deleted significant testing that would have provided additional knowledge on V-22 flying qualities and susceptibility to vortex ring state"—testing that might have helped prevent the deaths of 19 Marines in December 2000. Meanwhile, faulty parts and design deficiencies remain and further jeopardize missions and lives.

The V-22 should not be deployed in combat; an alternative, most probably an in-production helicopter, should be selected to replace all V-22s.

Have we learned anything at all after 25 years, $18 billion, and 30 deaths? It seems not. But if we act quickly, we can still save lives.

THE V-22 OSPREY— WONDER WEAPON OR WIDOW MAKER?

They warned us—the Marine Corps, the Government Accountability Office, the Pentagon's Director of Operational Test and Evaluation. But no one is listening.

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Wars missed

The world's first combat tiltrotor squadron, Marine Medium Tiltrotor Squadron 263 (VMM-263), finally came into being in March of 2006. Its pilots include two women and range in experience from Iraq combat veterans (one third) to recent flight school graduates (almost one third).[1] VMM-263, known as the "Thunder Chickens," and their MV-22 *Osprey*s, will be deployed to Iraq in 2007, according to Lt. Gen. John G. Castellaw, deputy commandant for aviation in the U.S. Marine Corps. "We're conducting the tactical training… Next year we're going to put it into combat with great confidence," said Castellaw.[2]

The MV-22's combat deployment will thus occur roughly 18 years after the V-22's first flight on March 19, 1989.

As for deploying the V-22 for use in Afghanistan, "We estimate our efficiency in the Afghan scenario would have improved by 65 to 75 percent had we employed the V-22," commented Marine Corps Gen. James Jones at the Farnborough Air Show in July 2002.[3] He said that lives would have been saved. Others probably would also be quick to claim that the MV-22, able to take off and land like a helicopter and transition to level flight at the speed of a turboprop feederliner, would seem to have been ideal for covert insertion of special operations teams and transport of Marine expeditionary units into northern Iraq at the start of *Operation Iraqi Freedom*.

Well, it did not happen. Despite the *Osprey*'s first flight in 1989, it missed Bosnia six years later in 1995, Afghanistan 12 years later in 2001, Iraqi Freedom 14 years later in 2003, and potential

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1 Montgomery, Dave. (2006). "Marine Squadron Training for Combat Flights." *Star-Telegram,* June 21, 2006. Last retrieved on Sept. 15, 2006, from http://www.dfw.com/mld/dfw/news/14867554.htm.

2 Whittle, Richard. (2006). "V-22 is going to war, Marine general says." *Dallas Morning News.* May 5, 2006. Last retrieved on Sept. 15, 2006, from http://www.dallasnews.com/sharedcontent/dws/bus/stories/DN-V22_05bus.ART.State.Edition1.dd0a295.html.

3 Derby, Paul. (2002). "*Osprey* 'could have saved lives' in Afghanistan." *Flight International*. July 23, 2002. Last retrieved on Sept. 26, 2006, from http://www.flightglobal.com/Articles/2002/07/23/152028/*Osprey*+'could+have+saved+lives'+in+Afghanistan+.html.

Katrina and Rita rescue operations in 2005. Although it is now about to enter full production after being in development for 25 years—more than six times as long as U.S. involvement in World War II—it is, in fact, still not ready.[4]

During the V-22's development, 30 people have died—and now this glitch-plagued program that survived one cancellation and numerous problems is poised to reveal fundamental design flaws that may cost even more lives: the *Osprey*, though partially fledged, has been nudged from the nest and cleared for combat. But enemies are not the only ones at risk. Despite the best hopes of three military services planning to use this aircraft, the V-22 has turned out to be the product of flawed design exacerbated by failure to build and evaluate a preliminary full-scale mock-up—jeopardized further by a botched testing program in which key exercises exploring potentially dangerous flight conditions were omitted or cancelled. Secretary of Defense Richard Cheney killed the program in 1989, but Congress revived it shortly thereafter. Quickly it evolved into a bulletproof juggernaut that could not be cancelled because it had gained too much political momentum—as a special blue-ribbon panel would later conclude.

The situation is most unfortunate, for in airplane mode in level flight, the V-22 is faster than any helicopter and can leap vertically to lift troops and supplies to otherwise inaccessible locations behind enemy lines. Indeed, the V-22's "*Osprey*" designation would seem to epitomize the concept of a super-craft that can swoop, raptor-like, onto an enemy with deadly results.

That's why the Marine Corps asked for 360 MV-22s. Dazzled by the *Osprey*'s advertised advantages over helicopters in transit speed and range, the Corps came to see them as critical to its 21st century Operational Maneuver from the Sea doctrine, requiring airlift of troops and supplies from beyond the horizon directly to inland positions, bypassing vulnerable beachheads. For its part, the Air Force also wants 50 CV-22s to replace its over-age MH-53J helicopters (long out of production) for use in special ops, while the Navy has said it would like 48 for duties including search and rescue, aerial tankers, and carrier-on-board delivery of critical supplies. Even the Israeli Air Force has expressed serious interest in procuring V-22s: according to *Jane's Defence Weekly*, they would be used for search and rescue as well as insertion/extraction of its special forces.[5]

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4 For perspective, consider that the V-22's combat début will cap an unprecedented 26-year span stretching across more than a quarter century from concept approval to initial deployment. Now contrast *Osprey*'s long and problem-plagued development with the transformational Polaris ballistic missile and submarine program, which rocketed in just four years from formal project initiation in December 1956 to "15 November 1960, [when] the *USS George Washington* (SSBN-598), the first U.S. nuclear-powered ballistic-missile submarine, went to sea on deterrent patrol with 16 Polaris missiles" [Polmar, Norman. (June 2006). Polaris: A True Revolution. Proceedings, (132/6/1)240, 31]. Polmar reminds us that before Polaris there had been 1) no U.S. solid-fuel intermediate- or long-range ballistic missile, 2) no U.S. ship equipped to launch a long-range ballistic missile from the surface or submerged, and 3) no complex computer-controlled Ships Inertial Navigation System (SINS), which had been hastily expanded from the system developed for the recently cancelled X-10 Navaho, precursor to a land-based, 5,000-mile range ramjet-powered intercontinental nuclear missile. All these developed, tested, and integrated into the comprehensive Polaris submarine thermonuclear ballistic missile weapons system—in a roughly four-year timeframe.

Thus the Soviet Union faced a sudden and challenging paradigm shift in U.S. nuclear missile strategy and deployment—one for which it had no reliable countermeasures, one that may well have shifted in U.S. favor the balance of terror during the hair-trigger days of the Cuban Missile Crisis almost two years later.

5 Ben David, Alon. (Feb. 1, 2006). "Israel considers V-22 Acquisition." *Jane's Defence Weekly*. 43(5), 16.

As for the United States, given that the *youngest* of the Marines' geriatric CH-46 helicopters closed down its production line 36 years ago, the remainder of this rapidly shrinking fleet has become an overwhelming challenge and expense to maintain. Could the Marine Corps replace them with modern, "new-build" helicopters? Yes; and at far lower cost than with the V-22. The options include:

- **AgustaWestland's US101 (EH-101):** three engines, single rotor; recently selected as the U.S. presidential transport helicopter under licensed assembly arrangements with Lockheed Martin as prime contractor; capacity of 30 combat-equipped troops (more than *Osprey*);
- **Boeing's CH-47F *Chinook:*** two engines, two rotors; able to carry 33 combat-equipped troops (more than *Osprey*), and currently in production; and
- **Sikorsky's H-92 *Superhawk:*** two engines, single rotor; 22 combat-equipped troop capacity.

But, beguiled by initial performance promises and despite developmental deficiencies, the U.S. Marine Corps has remained loyal to its original and very expensive choice of the V-22 *Osprey*. Today, decades later, for the Corps there is no greater assault transport need—whatever the platform. And for all three services, there seemed initially to be no greater promise than the V-22.

"But for the Marines, this is their plane," says Lawrence J. Korb, a senior advisor for the Center for Defense Information and former assistant secretary of defense in charge of manpower, reserve affairs, installations and logistics. "It's symbolic. They have put all their eggs in this basket."[6] Tragically, four of those eggs have already been broken—so now, for members of VMM-263 and others who will soon fly the *Osprey* into combat, there may be no greater risk.

A new technology

While the MV-22 is supposed to epitomize 21st century 'cutting edge' technology, in fact the quest for such a V/STOL transport aircraft has been a multinational endeavor reaching back more than half a century. Both the V-22 *Osprey* and its smaller civilian scion, the BA-609, trace their lineage to numerous predecessor aircraft. To cite just a few: Transcendental's primitive 1-G tiltrotor of 1954; 1955's Bell XV-3 tiltrotor and the Vertol V2-2 tiltwing; Russia's 1955-6 Brathukin twin-turboprop tilt-wing conceptual study; the Doak V2-4 tilt-ducted fan of 1958; the 4-engine LTV-Hiller-Ryan XC-142 tilt-wing of 1964; Canada's CL-84 *Dynaver* of 1965; and finally, Bell's 1966 X-22 tilt-quad-ducted fan and its 1980 XV-15 tilt-prop, the latter of which was dramatically demonstrated at the 1981 Paris Air Show. Indeed, the implied potential of the XV-15 resulted in the award later that year of the contract for a conceptual study that led to development of the V-22 and flight of the first prototype on March 19, 1989—over 17 years ago.

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6 Wayne, Leslie. (July 19, 2006). "For The *Osprey* Hybrid Aircraft, Zigzags To Cap 20 Years Of Zigzags." *The New York Times*, C-4.

And the conceptual transition from helicopter to its intriguing and apparently successful lightweight XV-15 tilt-rotor godfather to the V-22 itself evolved into a similar paradigm shift from helicopter descent utilizing relatively low rpm (180 rpm) traditional low-twist (usually about 8 degrees) extended-length flexible rotor blades to the V-22's vertical descent relying on much stiffer, shorter-span, high-twist (47 degrees) modified propeller blades spinning at 333 rpm in horizontal cruise and 397 rpm in vertical climb or descent.[7] Thus it was that the radical and far heavier V-22 entered an unexplored realm fraught with aerodynamic unknowns.

Crashes

It proved to be an ominously uncertain world. As development continued, the V-22 *Osprey* was plagued by a series of dangerous crashes—three of them deadly—starting 15 years ago in 1991:

- Crash 1: June 11, 1991. Assembly carelessness caused incorrect wiring of two out of three of its roll gyroscopes, resulting in erratic flight and the crash of *Osprey* #5 shortly after vertical takeoff.

- Crash 2: July 20, 1992. Leaking oil pooled in the bottom of the number two (right) engine nacelle during level flight only to be ingested into the engine during transition to hover mode prior to landing. Fire erupted. An advertised safety feature is the V-22's theoretical ability to fly with the one remaining engine powering both rotorprops via the complex multi-jointed cross-wing Interconnect Drive System (ICDS). In this case, however, "heat of the fire also disabled the cross shaft."[8] *Osprey* #4 crashed. Seven people died.

- Crash 3: April 8, 2000. As part of the previous round of operational testing, a challenging simulated nighttime rescue of embassy personnel from a hostile neighborhood required instrument approaches and high-rate-of-descent formation landings at an airport near Tucson. In the process, V-22 #14 crashed, killing all 19 Marines on board.

As the Defense Science Board Task Force on Test and Evaluation would report in December of that year, "In order to save dollars and make up for schedule slips, the important FCSDFQ [Flight Control System Development Flying Qualities] testing was severely curtailed."[9] The task force reported that the Marine Corps' own investigation of the accident "makes that point

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7 "The V-22's well-engineered systems allow pilots a smooth transition from helicopter or fixed-wing aircraft." North, David M. (Dec. 14, 1998). "V-22 *Osprey*: The Airplane That Hovers." *Aviation Week and Space Technology*. 149(24), 54. Last retrieved on Sept. 15, 2006, from Lexis-Nexis Academic.

8 Ibid.

9 Report of the Defense Science Board Task Force on Test and Evaluation. (December 2000). pp. 27-28. The testing statistics cited in this report and the Marine Corps' own investigative analysis will appear later on pg. 23 of the GAO's Feb. 20, 2001, report to Secretary of Defense Donald Rumsfeld, cited frequently in the following pages. Anonymous (personal communication, section excerpted from report and e-mailed to author on June 22, 2006; sender's name withheld by request).

in spades,"[10] quoting from Section VII of the Marine Corps report's findings: of the 103 test conditions to be flown, "in an effort to recover cost and schedule, the conditions to be tested were reduced to 49. …Of the 49 conditions, 33 were flight-tested. …16 conditions not flown were those at zero knots and 20 knots and at 40 knots and 80 knots at high gross weight."[11]

That the tests addressing flying qualities and a phenomenon called "vortex ring state" (VRS, explained below) were reduced from 103 mandated test conditions to the 33 actually flown represents ***cancellation of almost 68 percent of the tests in this key area****—including the crucial two at 20 and 40 knots at high gross weight specifically applicable in this accident.* That aircrews were tasked with participating in that April 8 night operation without benefit of such highly relevant test results and experience represents real—and what some might label criminal—negligence on the part of those NAVAIR and Marine Corps leaders who knew both the parameters of the missing tests and the nature of this nighttime exercise. Without this prior testing experience, data, and subsequent analysis, these pilots should not have been flying such a mission as part of OT-IIE.

But they flew their mission as ordered, and then the pilot, wearing new-model night vision goggles and already in helicopter mode, had to make a sudden adjustment to his approach when the aircraft immediately ahead of him slowed both its descent rate and forward airspeed. Trying to avoid overtaking the first aircraft, he decreased his forward speed to about 25 knots, but increased his descent rate to roughly 2,400 feet per minute (fpm). At about 300 feet above ground level, his aircraft is thought to have had one of its rotors suddenly encounter a combination of blade stall and the vortex ring state phenomenon, drastically losing thrust. With the other rotor still producing normal thrust, the *Osprey* went into a snap roll and crashed.[12] Some ground reflected turbulence and unstable air trailing in the wake of the first aircraft may also have served as catalysts for the onset of the treacherous aerodynamic phenomena triggering the accident. Notably, this maneuver involved formation flying adjustments, not combat.

Could the omitted testing have helped prevent this tragic accident? Were specific tests also ignored, that aimed to "[i]nvestigate the potential for airflow interactions between nearby V-22s to initiate or aggravate vortex ring state"?[13] (For an in-depth look at the nature of vortex ring state, blade stall, and the dangers they pose to this aircraft, see the discussion on vortex ring state and blade stall below.)

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10 Ibid.

11 "Investigations into the Circumstances surrounding the Class 'A' Aircraft Mishap Involving an MV-22B *Osprey* Bruno 165436 That Occurred on 8 April 2000 at Marana Northwest Regional Airport Near Tucson, Arizona," 74. Anonymous (personal communication, section excerpted from report and e-mailed to author on June 22, 2006; sender's name withheld by request).

12 Details taken from the account given by Nelms, Douglas W. (2004). "Saving the *Osprey*." *Rotor and Wing/Aviation Today.* Oct. 20, 2004. Last retrieved on Sept. 26, 2006, from http://www.aviationtoday.com/cgi/rw/show_mag.cgi?pub=rw&mon=1004&file=savingtheosprey.htm.

13 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 33. Last retrieved on Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.

- Crash 4: Dec. 11, 2000. During approach to New River, N.C., air station after a night training mission, as it transitioned from aircraft to helicopter mode, *Osprey* #18 experienced dual hydraulic failure, leaving one hydraulic system still operable. With multiple crew alert lights flashing on the cockpit console, the pilot punched the system reset button, attempting to verify which faults were valid. A software flaw then caused the flight control system to neutralize prop blade pitch angle; the aircraft slowed, yawed. When the pilot pushed reset several more times, trying to solve the problem, blade pitch reset yet again, severely jarring aircraft and crew. The aircraft stalled and crashed. Four Marines died.[14]

Of the four crashes, three were triggered by below-standard parts, software and/or bad assembly line quality control. The other was caused by an encounter with a dangerous aerodynamic phenomenon that continues to hover mercilessly at the edge of various rotorcraft maneuvers, after specific tests to investigate methods of operating within this phenomenon—widely recognized as a potential problem—had been cancelled.

With the death toll at 30, all V-22s were grounded for almost a year and a half for engineering modifications, systems evaluations, and quality assurance checks. A blue-ribbon panel, specifically convened to investigate, eventually granted clearance for resumption of testing,[15] but since flights resumed at the end of May 2002, little seems to have changed in terms of design flaws or quality control. Luckily, despite numerous mishaps, there have so far been no new fatalities.

Since then, further in-flight anomalies have included newly installed panels flying off, an oil cooling fan disintegrating, and flight control software problems triggering uncommanded side-to-side oscillations. Looking ahead to the imminent biennial Farnborough air show and exposition, it is little wonder that on July 13, 2004, more than two years after the improved *Osprey* had re-entered flight testing, London's *Financial Times* reported that "a Pentagon plan to exhibit its new V-22 *Osprey*, a tilt-rotor aircraft that can fly like an aeroplane or a helicopter, was scuppered because of continuing glitches."[16]

Vortex ring state and blade stall comprise the most dangerous and complex issues facing this program.

We are not talking here about "glitches," or subcomponent quality control issues, or assembly line carelessness problems. It is an aerodynamic enigma involving highly complex turbulence conditions beyond the analytic capabilities of our most advanced computational fluid dynamics simulations.

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14 Details taken from the account given by Nelms, Douglas W. (2004). "Saving the *Osprey*." *Rotor and Wing/Aviation Today.* Oct. 20, 2004. Last retrieved on Sept. 26, 2006, from http://www.aviationtoday.com/cgi/rw/show_mag.cgi?pub=rw&mon=1004&file=savingtheosprey.htm.

15 Former Secretary of Defense William Cohen appointed John R. Dailey to chair this panel. Dailey had thousands of hours of piloting experience in both fixed-wing aircraft and helicopters—impressive credentials for this assignment. But as a retired general and former assistant commandant of the Marine Corps for aviation, Dailey clearly also had strong ties to the Corps and to the V-22 program the Marines deemed so essential. If Cohen was looking for a completely objective assessment, how could he have avoided noticing these very apparent conflicts of interest?

16 Spiegel, Peter. (July 13, 2004). "High-flyers who snubbed Paris will jet into London." *The Financial Times,* 22. Last retrieved on Sept. 22, 2006, from Lexis-Nexis Academic.

Given that the V-22's dual-mode flight capability (as either helicopter or airplane) requires significant aerodynamic design compromises in its prop blades in an attempt to maximize their efficiency in both flight modes, the blades' stiff, high-twist (47 degrees) design necessary for the higher speed horizontal flight mode poses severe danger when employed in rapid vertical descent situations likely to be faced in combat. This is, therefore, an essentially irreconcilable design conundrum that unfortunately cannot be 'resolved.' And it will pose especially dangerous challenges under the stresses of combat.

As the OT-IIG report states, "When descending at a high rate with low forward speed, the rotor can become enveloped in its own downwash, which can result in a substantial loss of lift. … Should one rotor enter VRS and lose more lift than the other rotor, a sudden roll can result, which quickly couples into a[n inverted] nose-down pitch"[17]—i.e., an upside-down nose-first crash. Such a maneuver at low altitude during high rate of descent into a hot landing zone would therefore result in catastrophic loss of the aircraft and all aboard. Yet we are told that program managers "have confidence that the V-22 VRS characteristics, operational limitations, and consequences are now well understood."[18]

The *consequences* of VRS may well be understood, especially following the third *Osprey* crash that killed 19 Marines—but not, according to some of the best scientific minds in the country, the precipitating conditions or causes. Consequences, we now know, include sudden departure from controlled flight, quick roll, and inverted dive into the ground. One can understand temptations to mandate "operational limitations"—but such limitations severely curtail the *Osprey*'s combat maneuvering capability as it enters its most vulnerable phase—descent into heavily defended landing zones. Unable to maneuver appropriately during rapid descent, it can be shot down all too easily, probably with the potential loss of all on board.

Such characteristics are unique to the *Osprey* because of 1) its 47-degree rotorprop blade twist, 2) its rigid blades, 3) an empty-weight potential disk-loading roughly 2.68 times that of a CH-53A Sea Stallion (one of the helicopters the V-22 is replacing)[19] and 4) a wingtip-mounted, longitudinally center-of-gravity-sensitive and roll-vulnerable dual-prop overall design.

For the *Osprey* and its occupants, VRS onset therefore occurs 1) more suddenly, 2) over a wider range of flight conditions, and 3) more violently than with helicopters.

The Pentagon's report tells us that OT-IIG ran flight tests to address the problem, that "rapid recovery has been demonstrated by rotating the nacelles forward at the first sign of VRS,"[20] that aircrews were able to accomplish their missions "within the flight restrictions

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17 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 18. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

18 Ibid., 18.

19 V-22 empty at 33,140 pounds vs. CH-53A at 22,444 pounds. Rotor radius 19 feet on each V-22 three-blade rotor; 36.13 feet on the single CH-53A six-blade rotor.

20 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 18. Last retrieved on Sept. 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

ensuring that the aircraft remains out of the VRS-susceptible envelope."[21] That sounds good, but it makes no mention of the altitude at which those recovery exercises were run, where the nacelle would be able to tilt forward 16 degrees over a 2-second period, resulting in probable abort of any descent profile in progress. The altitude, however, is discernible in context: they were at thousands of feet. Such altitude and time are unavailable luxuries during rapid troop insertion under fire passing through low altitude. As for "flight restrictions ensuring that the aircraft remains out of the VRS-susceptible envelope,"[22] consider that the current 800 fpm descent restriction translates to 9.1 mph—*40 percent slower* than those blinking signs tell you to drive as you slowly pass through the school zone at 15 mph.

Thus the "solution"—to descend ever so slowly (at 9.1 mph) in vertical flight into any landing zone—is a speed so slow that the rotorcraft becomes an easy target for even relatively primitive hand held infantry weapons, such as AK-47 assault rifles and RPG unguided rocket launchers. In the case of enemy-defended ("hot") landing zones, it is an unavoidable "Catch-22": if an MV-22 pilot, concerned about hostile fire, tries to ignore the VRS flight restrictions (and instrument warning lights) so that he can get his 24 Marines on the ground ASAP before being knocked out of his descent by an enemy's weapons, he may well trigger a deadly combination of blade stall and vortex ring state and crash—with deadly consequences.

These are, unfortunately, innate and potentially fatal design *characteristics of this aircraft and its unique propellers, characteristics that cannot be eliminated given current scientific knowledge of the technical issues.*[23]

Unfortunately, given *Osprey*'s level flight requirements, the same blade design characteristics required for higher-rpm rotorprops and turboprop feederliner speed cause difficulties and uncertainties in vertical flight, especially during descent. It's a nasty paradox.

As to the radically evasive maneuvers and high speed vertical descent necessary in combat when going into heavily defended landing zones, as newscaster Ed Murrow used to say, "Good night, and good luck."

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21 Ibid., 18.

22 Ibid., 18.

23 To explain further the unusual nature of the V-22's fragile flight envelope at high rates of descent, let me summarize selected findings from "Blade Twist Effects on Rotor Behaviour in the Vortex Ring State," an aerodynamic study by Brown, Leishman, Newman, and Perry. "The onset of VRS," they write, "…is not solely determined by the operating conditions of the rotor, such as descent rate and forward speed, but is also dependent on details of design of the rotor such as the *degree of twist incorporated into the blades* [author emphasis]. …Blade stall also plays an important role in governing the behaviour of the rotor in the VRS" [Brown, R.E., Leishman, J.G., Newman S.J., and Perry, F.J. (2002). *Blade Twist Effects on Rotor Behaviour in the Vortex Ring State.* Presented at the European Rotorcraft Forum, Bristol, England, September 17-20, 2002 (p. 14)]. Last retrieved on Sept. 27, 2006, from http://www.enae.umd.edu/AGRC/Aero/ERF_2002.pdf. (Further footnote references to this source will cite BTE followed immediately by the page number.)

And, of course, blade twist is a key determiner of blade stall occurring when smooth laminar flow along the blade's upper surface is replaced by boundary layer separation and turbulent flow occurring at high blade airfoil angles of attack relative to local airflow, a condition especially prevalent during vertical descent. (Continued on p. 17)

But fear not—a brand new high-tech solution waits in the wings…so we are told. In 2002 Boeing was given an Office of Naval Research contract to develop a reconfigurable rotor blade that would use shape-memory alloys to change the twist of the prop blades in flight to maximize efficiency whether in airplane mode (using high twist) or hover mode (employing minimal twist). Potential benefits included 3,000 pounds of additional payload or a 30 knot increase in forward speed.[24] One would assume, too, that decreased blade twist (and resultant angle of attack) would delay blade stall and/or VRS during rapid vertical descent.

A bench test of a full-scale system employing memory alloy actuators was originally projected for December 2006. Alas, three years went by until a follow-on report in *Flight International,* on Nov. 1, 2005, indicated that for three years the Navy had restricted funding to 40 percent of the promised level—restoration to roughly the 90 percent level not occurring till 2005 and 2006. The result? At least a two-year delay in testing the NiTinol-fitted actuators employing temperature change to alter the twist angle of the prop blades—at an additional expense of $6,000 per blade ($36,000/aircraft), not counting development and other system installation costs. (There was no mention of the weight this system would add to the aircraft.)

The upshot, of course, is that in pursuing this putative remedy, the program is now attempting to correct a critical deficiency peculiar to the introduction of a radically new technology (deployment of tiltprop aircraft into combat) through retroactive injection of an even newer and hitherto untested technology. The outcome is still unknown.

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23 (Continuted from p. 16) With the V-22, the significant 47 degree blade twist close to the hub triggers cascading aerodynamic consequences that slide outward along the blade even as the twist gradually decreases, and then backward into the now-disturbed airflow through the rotor disk—creating conditions ripe for the emergence of vortex ring state.

Given sufficient altitude, recovery from VRS in the MV-22 involves straightforward advancing of the cyclic to tilt the proprotors forward 16 degrees over two seconds. (Helicopters use similar recovery procedures.)

But VRS is aerodynamic Russian roulette: an unpredictable and potentially deadly game one should not play, for "geometrically similar helicopters may exhibit different handling characteristics when flown in the VRS…for no clearly understood reasons."[BTE3] At the root of these issues is, of course, the intrinsically chaotic nature of wake turbulence, the unavoidable fact that "rotor wake is inherently unstable in most flight regimes, including in hover, and…increasing the rate of descent makes the wake more prone to instability."[BTE3] In looking at "the precursor to the *nonlinear* [author emphasis] growth mechanism that eventually leads to rotor wake breakdown in the VRS,"[BTE3] the study states that "the problem of wake stability has been examined under various operating conditions using a *linearized* [author emphasis], eigenvalue analysis of the rate of growth of perturbations to the vortical structure of the rotor wake."[BTE3]

In plain English, we are being told that, even with computers programmed with the most advanced computational fluid dynamics software, we are at the edge of our computational envelope, doing the best we can with traditional linear mathematics to analyze nonlinear conditions hovering in the realm of chaos theory. (Readers interested in unsettling aerodynamic ramifications associated with high-twist V-22 prop blades may wish to consult the short Appendix following the main text of this article.)

24 Lewis, Paul. (2002, Sept. 3). "Boeing aims for V-22 rotor twist; Navy tries to counter tiltrotor criticism with shape memory alloy actuators to boost hover and forward flight modes." *Flight International,* 32. Last retrieved on Sept. 27, 2006, from Lexis-Nexis Academic.

Once again, the obvious has been ignored: "Of critical importance is demonstrating the technical maturity of the technologies embedded in a new system development prior to proceeding into accelerated development."[25]

Possibly available, however, are potentially beneficial adjustments not requiring new technologies. For example, it has been known for years that blades have been successfully added to Bell's *Huey* helicopter, the Lockheed Martin C-130J Hercules II (six blades replacing four), and other aircraft to provide significant improvements in performance—now including even an 8-bladed C-130E being tested under contract with the Defense Advanced Research Projects Agency.[26] The same could still be done for later blocks of the V-22 if NAVAIR pulled a Block A MV-22 out of storage, modified it, tested it, and verified that safety and performance improvements would result from rotorprops with more than three blades.

Indeed, one expert consulted by this author confirmed the validity of this concept, citing a retired V-22 aeroengineer who insisted on just such a design correction early in the program.[27] Responding to a query from the press, this engineer explained that "as the number of blades increases, … the performance in the helicopter mode also increases. With a choice of four or five blades …all of the factors involved in hover, downwash, autorotation [currently impossible with three blades], and maneuverability, along with aircrew safety, would have been improved significantly. … [A] selection of five blades would also have significantly reduced (or completely eliminated) the probability of loss of control in … blade stall and vortex ring state." [28] But since the co-manufacturers chose not to change a design they had already settled on, for his efforts this aeroengineer was fired by the Bell-Boeing prime contractor team.[29]

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25 Christie, Thomas. (February 2006). "What Has 35 Years of Acquisition Reform Accomplished?" *U.S. Naval Institute Proceedings,* 35. Last retrieved on Sept. 22, 2006, from http://www.cdi.org/pdfs/Christie%20in%20Proceedings.pdf.

26 Ed. Phillips, Edward H. (April 3, 2006). "Industry Outlook: Herc Perk." *Aviation Week & Space Technology,* 13.

27 Col. Harry P. Dunn (USAF, ret.) has three engineering degrees, including two in aeronautical engineering. His flight experience includes 5,000 hours in multi-engine aircraft and helicopters. He was initiator and director of the world's first in-flight helicopter refueling program, served a tour in Germany supervising training and check-out of German helicopter pilots, flew combat missions in Vietnam in both helicopters and fixed wing aircraft, and was elected as a charter member to the Aviation Hall of Fame.

28 Ibid.

29 Included in Dunn, email forwarded to author Aug. 14, 2006. Original email containing this information was sent on Sept. 4, 2001, to a list of recipients that included Edward C. "Pete" Aldridge (DOD Undersecretary for Acquisition, Technology and Logistics), Norm Augustine (former CEO of Lockheed-Martin and member of the V-22 blue-ribbon panel cited earlier in this text), Sen. John Warner (Chair, Senate Armed Services Committee), Sen. John McCain (member Senate Armed Services Committee), and others. Dunn adds that because of the MV-22's blade-fold requirement for shipboard storage, four blades could be handled more easily; five, though aerodynamically preferable, would pose major folding problems.

Quality control

Prime contractor Bell-Textron achieved International Standards Organization (ISO) 9001 certification on Dec. 1, 1997, followed in September 1999 by Boeing's Ridley, Penn., rotorcraft plant, the producer of *Osprey*'s composite fuselages. Assuredly, certification by this noted international non-governmental benchmarking association founded in 1947 comes only after internal reviews and third-party assessment covering "every phase of design, fabrication, assembly and quality inspection" (to cite just a few of the areas listed in Boeing's Sept. 15, 1999, news release). [30] According to that same document, such certification ensures that the facility's rotorcraft and aerospace programs are "fully compliant with world-class production and quality standards."[31]

What have these "world-class production and quality standards" given us?

During the operational evaluation preceding the fourth crash, "the hydraulic power system suffered 170 failures"[32] and was underscored as a significant problem area by Philip Coyle, the Pentagon's director of operational test and evaluation at the time, after all V-22s were grounded following that crash in December 2000.[33]

Result of the stand-down and mandated modifications and improvements? Following May 2002's resumption of flight testing, in March 2003 V-22 flight operations were suspended yet again when production lots of 1-inch hydraulic lines powering the swash plate actuators were found to be below standard. And on Aug. 4, 2003, an *Osprey* suffered failure of one of the hydraulic systems powering its flight controls and quickly landed near Washington, D.C. Later that month, V-22 #34 (in flight at 9,000 feet) shed a newly installed inspection panel, which then smashed a large hole in the right vertical stabilizer—and, following repairs, had to shut down again when the right-hand proprotor gearbox popped a filter circuit and triggered a warning light. Shortly thereafter, on Aug. 28, aircraft #28 started up at Patuxent River test station and while still on the hardstand, generated such powerful downwash that resultant flying debris shattered the windshield of aircraft #21 parked nearby. August 2003 was not a good month.

There's more. Over North Carolina on Dec. 2, 2003, part of a propeller sheared off a V-22 and tore into its left wing, prompting a premature landing. (Less than a year later, an *Osprey*

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30 Boeing. (Sept. 15, 1999). Boeing Rotorcraft in Philadelphia Achieves ISO 9001 Certification. Last retrieved on Sept. 28, 2006, from http://www.boeing.com/news/releases/1999/news_release_990915n.htm.

31 Ibid.

32 Wall, Robert. (Jan. 1, 2001). "V-22 Hydraulic Woes Strike Again." *Aviation Week & Space Technology,* 154(1), 32. Last retrieved on Sept. 22, 2006, from Lexis-Nexis Academic.

33 Given the hydraulic system failure rate, it is disturbing to read that former Bell employee Douglas W. Williams reported that in November 2000, "Bell was informed by one of its suppliers that some hydraulic line fittings for the V-22 were faulty" and was requested to return all fittings—both installed and uninstalled. Williams apparently charged that "Bell did not remove parts already installed." Williams told the interviewer he was fired by Bell "for threatening to reveal improper activities"; he then filed a Federal False Claims Act lawsuit to that effect against Bell. Williams' lawsuit was subsequently dismissed, but in November 2003 the Defense Department began its own investigation into allegations against Bell. (Quotations from Cox, Bob. (Dec. 13, 2003). "Bell is Facing Federal Scrutiny." *Star-Telegram*, 1C.

would make an emergency landing in Canada after another propeller flung off a 20-inch section of blade). On Dec. 12, 2003, a software-generated oscillation problem in aircraft #10 at Patuxent River prompted NAVAIR to restrict most V-22s from aggressive maneuvering or flying at more than 10 degrees angle of bank in helicopter mode. Subsequently, on March 9, 2004, aircraft #43 (previously a victim of electrical problems) had to make an emergency landing in Georgia following a lube system failure advisory. Other "minor" problems were soon found in that aircraft—requiring that experts be flown in from Bell Helicopter Textron and Boeing.

June saw another *Osprey* make an emergency landing aboard the amphibious assault ship *Iwo Jima* off the Virginia coast after deck crew heard unusual noises and saw parts spewing from the front of one of the engines as the oil cooler fan disintegrated.

Six other premature landings between April 2004 and the end of January 2005 followed cockpit alarms triggered by lubricant contaminated with chrome flakes shed from gearbox bearings manufactured by Timken and plated by Armoloy. On March 28, 2005, an engine of V-22 #53 erupted in flames when a leaking hydraulic line dripped fluid onto hot engine parts. (Remember the hydraulic leak contributing to crash number four more than four years earlier?) Following the Pentagon's positive 2005 OT-IIG report that set the stage for full-rate production approval, on Oct. 18 a CV-22 with a non-working deicing system flew into clouds over Arizona and encountered 10-15 minutes of icing conditions. Accumulated ice broke loose and damaged the tail and other parts of the aircraft, including the engines—which had to be replaced after its unscheduled landing at Prescott.[34]

That's just a sampling.

These represent "world-class production and quality standards" we can expect from ISO-certified Boeing, Bell-Textron, and their subcontractors? And what is one to think of the maintenance process, the integrity and validity of the testing and evaluation program, when we learn that two and a half weeks after four Marines from VMMT-204 had died in that fourth crash, Lt. Col. Odin F. Leberman, commander of that same training squadron, ordered its maintenance crew to fudge their V-22 maintenance records to make the *Osprey* look good?

And we have yet to address basic design flaws.

What kind of bird is this *Osprey*?

Is it the fearsome raptor that some claim? Others viewing the V-22 might see a genetic mix of Phoenix (rising from the ashes of Cheney's cancellation) and, when heavily loaded, a barely flyable Turkey—indeed, a burdensome Albatross around the neck of the Marine Corps, Air Force, Navy, and the American taxpayer.

The problem is that the V-22 gained irresistible momentum in its additional incarnation as the generous Goose laying golden eggs in 45 out of our 50 states. Take jobs, for example:

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34 Fulghum, David A. (Oct. 31, 2005). "Ice Test; CV-22 suffers engine and tail damage from ice during ferry flight from Texas to California." *Aviation Week & Space Technology*, 28. Last retrieved on Sept. 25, 2006, from Lexis-Nexis Academic.

2,000 *Osprey*-related jobs were created for Bell-Textron in Fort Worth and Amarillo, Texas, and more than 1,500 jobs were created for Boeing in Ridley Park, Penn. Jobs, of course, mean votes for congressmen and senators who bring the pork home to their districts.

Consider Rep. Curt Weldon, R-Penn., whose district includes the Ridley Park plant that manufactures V-22 fuselages. He commented to the Boeing workers following the Pentagon's authorization of full-rate production of the *Osprey*: "It's about a whole new generation of jobs."[35] Regarding Weldon, *Philadelphia Inquirer* writer Tom Infield reminded us that "he, more than anyone in Congress, helped preserve the V-22 *Osprey* program when the Pentagon wanted to kill it."[36] Weldon, of course, is vice chairman of the House Armed Services Committee and has his eye on the chairmanship—if he is reelected in November. Of the amount raised for his campaign by early May, "At least $292,000—about 40 percent of his total—has come from defense interests."[37]

Moreover, "In the early 1990s," reported John Wagner, "the UAW [International Union, United Automobile, Aerospace and Agricultural Implement Workers of America] launched a letter-writing campaign to Congress, making sure lawmakers were aware that killing the *Osprey* could cost them 8,000 union jobs."[38] Wagner also revealed that "Bell and Boeing have turned over *Osprey*-related work to companies based in 276 different congressional districts since 1992…That's 63 percent of all the U.S. House districts in the nation."[39]

Wagner also pointed out that during each of the previous three election cycles, Rep. Kay Granger, R-Texas, who represents the Fort Worth district, received $10,000 from Bell's PAC. During the 2000 elections, Boeing contributed more than $1.4 million to House and Senate candidates as well as various supporting Republican and Democratic committees; Textron, in turn, donated $474,000 to assorted candidates of both Houses and to their political action committees. Wagner's evidence leaves little doubt why Congress resurrected the *Osprey* after Cheney had stretched its neck across the chopping block.

And with the gift of initial low rate production, the program generated "momentum"—an estimated 70 (or more) V-22s produced by the end of April 2006 at a development cost of more than $18 billion, this out of a total estimated program cost of $50.5 billion.

Whatever happened to that once tried-and-true practice of the 1940s and 1950s (including Boeing's YB-52 and Convair's YB-60, for example) of building and flying proof-of-concept prototypes to test flight characteristics and work out engineering kinks before proceeding into full-scale development and initial production? As the Government Accountability Office

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35 Bender, William. (Oct. 1, 2005). "*Osprey* decision celebrated at Boeing." *DelcoTimes.com*. Last retrieved on Sept. 22, 2006, from http://www.delcotimes.com/site/index.cfm?newsid=15311770&BRD=1675&PAG=461&dept_id=18171&rfi=8.

36 Infield, Tom. (May 8, 2006). "For Weldon, a military campaign: Curt Weldon's deep and personal ties to the defense industry are paying off in his reelection bid." *Philadelphia Inquirer.* Last retrieved on Sept. 22, 2006, from Lexis-Nexis Academic.

37 Ibid.

38 Wagner, John. (March 27, 2001). "The Money and the Machine." *News & Observer*. Last retrieved on Sept. 22, 2006, from Lexis-Nexis Academic.

39 Ibid.

(GAO) had warned in 2001, "Knowledge of V-22 design and performance parameters falls short of what should have been known before beginning production."[40]

With the V-22, there was no wringing out of a prototype before initiating production; "concurrent development" was the new name of the game. Consequently, the blue-ribbon panel appointed to assess the program after four crashes and the loss of 30 lives "considered whether to cancel the program but decided that would be too expensive."[41]

Low-rate production continued, and five years later on March 24, 2006, *Market Watch* reported that the Pentagon was talking with Bell and Boeing about plans (subject to later approval by Congress) for a multiyear V-22 production contract for 185 aircraft for roughly $12 billion.[42]

Tipping point: the September 2005 OT-IIG Report

Opening the door to full production and the possibility of such a multiyear contract came with the September 2005 release of the Pentagon's "V-22 *Osprey* Program: Report on Operational and Live Fire Test and Evaluation," otherwise known as the OT-IIG Report. It was issued by the Office of the Director (under the signature of David W. Duma, Acting Director), Operational Test and Evaluation, whose seal on the title page reads: "Key to Weapons that Work." OT-IIG lasted from its first flight on Oct. 28, 2003, through June 18, 2005.[43] It is encouraging to read that "OT-IIG demonstrated that the MV-22 Block A is operationally suitable"[44] and effective in low and middle threat environments,[45] even as the report reassures us that the "MV-22 is compatible with flight and hangardeck operations."[46] But optimism converts to concern when the following page of the executive summary warns us that "current flight restrictions restrict the aircraft's ability while performing defensive maneuvers" to the extent that "current limitations may prove insufficient to counter threat systems"[47]—i.e., such flight restrictions might enable an enemy to shoot the aircraft down easily.

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40 Katharine V. Schinasi (Director, Acquisition and Sourcing Management), "Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production" (GAO-01-369R Defense Acquisitions), a report to Donald H. Rumsfeld, Secretary of Defense, Feb. 20, 2001. In 35 pages, this report includes a three-page cover letter to Rumsfeld, copy of the Jan. 12, 2001, briefing to the blue-ribbon panel formed to evaluate the V-22 program (Enclosure I, pp. 4-21), briefing support materials (Enclosure II, pp. 22-34) that also include quotations from the opinion section of an earlier JAG report), and a brief letter summarizing the Department of Defense's reaction to the GAO report (Enclosure III, p. 35).

41 According to Pentagon officials—in Bull, Leona C., (Oct. 4, 2002). "Pentagon urging Air Force to accelerate V-22 program." *Defense News.*

42 "V-22 *Osprey* adds achievements but criticism lingers." (March 24, 2006). *Market Watch.*

43 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 25. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

44 Ibid., 3.

45 Ibid., 1.

46 Ibid., 3.

47 Ibid., 4.

Indeed, one soon finds the report to be riddled with many disturbing anomalies and contradictions. Further investigation illumines events and situations showing convincingly that the V-22 *Osprey* is in fact a weapon that 17 years following its first flight still does not work and faces operational and aerodynamic challenges that will prove insurmountable in combat.

Such an assertion by this author warrants careful comparison of the report's findings with actual performance examples (including from within the report itself) and with evaluations of those involved in the tests. The Pentagon's V-22 OT-IIG report contains six parts: an executive summary; Section 1: Mission and System Description; Section 2: Test Adequacy; Section 3: Operational Effectiveness; Section 4: Operational Suitability; and Section 5: Survivability. This analysis will roughly follow the same format.

To prepare ourselves for some of the confusion we are about to encounter, it is helpful to realize that *as late as March 2003, 14 years after* Osprey's *first flight, no one in the test program yet knew who was responsible for doing what:* NAVAIR's March 27, 2003, Tech Review officially requested an "Org Chart of V-22 Class Desk/Program Office Hierarchy including description of who does what. This would be helpful in knowing who to get in touch with when the need arises."[48] No comment necessary.

Osprey missions

The V-22's missions will be multifold. For the Marine Corps, MV-22 tasks will include: over-the-horizon assault transport of troops from ship to objectives beyond the beachhead (possibly under fire), tactical recovery of aircraft and personnel, and re-supply of weapons and ammunition. The Air Force will use its CV-22s for rescue operations and insertion and extraction of special forces. Navy versions will perform carrier-on-board delivery of critical supplies as well as aerial tanker and rescue missions.

V-22 systems—what's in it, and what's missing?

The system description in the OT-IIG report highlights the V-22's unique engine installation, which boasts an ability to tilt from vertical to horizontal, plus a complex transwing interconnecting 10-segment cross-shaft (plus associated couplings and mid-wing gearbox) allowing either engine to power both props. But the *Osprey* is mistakenly described as a "tiltrotor" when it should be designated a "tilt*prop*" aircraft—not a minor difference, and one that embodies inherent aerodynamic dangers. More will be said about this error later.

The system description also boasts foldable prop blades and fully automated digital engine controls (FADEC) along with computerized self-diagnostic maintenance capabilities; it lists numerous advanced electronic warfare suites and redundant flight control system computers. Yet not all of these technologies work as advertised. Triply redundant hydraulic

48 NAVAIR. (March 27, 2003). *Osprey* V-22: *Tech Review*. Patuxent River, Md.

flight control systems might inspire confidence regarding survivability in combat, but they suffered many problems in initial testing. The OT-IIG report states that "no further chafing of hydraulic lines has been observed"[49] since the rerouting of hydraulic lines and the elimination of clamps that previously attached electrical wires to them. Testers felt confident that more than 5,000 flight hours with the MV-22 demonstrated that the "current hydraulic line configuration is safe for operation."[50]

But "operation" is not combat. In many areas of the wings and nacelles, the three brittle titanium 5,000 psi hydraulic lines often run parallel routes in very close proximity to each other. What happens when an RPG or 30 mm AA round explodes in the midst of such a nexus? Most likely, a rapid and complete loss of hydraulic pressure, followed by loss of aircraft control.[51] True triple redundancy would involve a totally different configuration of widely separated hydraulic lines in the V-22.

Warning systems abound—laser, missile, radar—but prohibitions against radical evasive maneuvering as one performs a final approach into a heavily defended landing zone negate the advantage of knowing where the enemy awaits you.

It is disconcerting to note, moreover, that the system description contains two egregious omissions: the *required* nose gun that was to sweep the landing zone and suppress enemy fire, and the personnel hoist *required* for quick, efficient insertion or extraction of individual troops in special operations or rescue missions. It is puzzling to imagine how individual personnel extractions will be performed behind enemy lines when the *Osprey* had to go through testing without its required personnel hoist and with its defensive maneuvering envelope severely restricted because of the dangers of either blade stall or vortex ring state in evasive maneuvers near the ground.

Osprey tested—sufficiently?

With the MV-22 soon to be deployed in desert environs, testing under brownout conditions—when the violent downwash blows up such a swirl of dust, dirt, and flying debris that the crew cannot see the ground and must land almost blind—is crucial. Yet we are told "VMX-22 did not encounter landings under conditions with severe visibility degradation during

49 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 19. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

50 Ibid., 19.

51 Such was the case with the American Airlines Flight 191 DC-10-10 that crashed in Chicago in 1979 when its entire port engine assembly separated from the aircraft on takeoff. As it arced up over the left wing, the pylon's "forward bulkhead severed four…hydraulics lines and two cables routed through the wing leading edge. … Two of these lines were connected to the no. 1 hydraulic system and two to the no. 3 system, providing backup to cope with a single hydraulic system failure" [Job, Macarthur. (1996). Air Disaster, Vol. 2., 57. Weston Creek, Australia: Aerospace Publications, Pty. Ltd.]. Result? Loss of hydraulic pressure—and backup—to the port wing's outboard leading edge slats, causing them to retract and precipitating the left wing's stall. The aircraft crashed; 273 people died. So much for hydraulic redundancy when lines run next to each other. And this was, obviously, not even in combat. (In the Lockheed L-1011, on the other hand, hydraulic lines routed through the wing are far more widely separated.)

OT-IIG … [because] an unusually wet spring resulted in a large amount of vegetation that prevented severe brownouts during landing attempts."[52] Why no re-testing at a later date in an appropriate locale? So much for critical testing that would have provided valuable insights into operation under conditions prevailing in Iraq, Afghanistan, or other desert-type locations where the *Osprey* may well see combat in 2007.

Furthermore, with the CV-22 version being developed for the Air Force, covert insertion and extraction of Special Operations Forces (SOF) will be a primary mission, many such clandestine operations occurring at night. Yet the test adequacy section of the report states that since the V-22 was inexplicably not equipped with a personnel hoist, the aircraft relied on a jury-rigged assemblage of "special personnel insertion and extraction (SPIE) equipment."[53] Moreover, "Although the test plan included 29 mission profiles … at night, they only accomplished 12."[54] That's only 41 percent of their objectives. The report provided no explanation of what would seem to be a significant testing inadequacy. Not only that, but just before the operational evaluation, "proprotor gearbox problems significantly curtailed flight operations. As a result, VMX-22 could not completely qualify the expected number of aircrew to conduct night operation aboard the ship."[55] One would expect these critical tests to be re-run after mechanical difficulties had been resolved, but this apparently was not done. The result? "The limited number of flight hours at night reduced the basis for evaluating night shipboard capability and crew fatigue issues."[56] This would not seem to represent "adequate testing" of a key mission parameter.

Other test exercises used "a ballast weight of 4,760 pounds in lieu of 24 combat equipped Marines,"[57] which translates to an underweight and highly unlikely estimate of 198 pounds per body armor-equipped Marine carrying rifle, ammo, and full combat pack: allowing a modest 60 pounds for all that gear puts each hefty Marine at roughly 138 pounds. That's *not* a realistic test. With five aircraft assigned to each mission, the outcome was that "two aircraft aborted the day mission because of mechanical failures,"[58] and "the test team had previously scaled back the night mission to three aircraft, of which one aborted"[59]—a 50 percent aircraft abort/cancellation rate with no live troops carried. The official summary of this operation borders on the inexplicable: "VMX-22 successfully executed the TRAP missions within the scope of aircraft and environments available for each mission."[60] As for recovery of personnel—in which the unprecedented violence of the downwash generated by high-rpm V-22 props could affect mission outcome? No simulated rescue mission of a pilot downed at sea was apparently

52 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 7. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

53 Ibid., 12.

54 Ibid., 6.

55 Ibid.

56 Ibid.

57 Ibid., 12.

58 Ibid.

59 Ibid.

60 Ibid.

performed during OT-IIG. A key question to consider: Would he or she drown first in the maelstrom generated by the descending V-22's brutal downwash?[61]

At night or by day, in flight or on deck, the V-22 is dangerously susceptible to sudden aerodynamic instabilities resulting from wakes of other aircraft during formation flight, disturbed flow fields downwind of the ship's superstructure, or turbulence generated by idling props of other aircraft preparing for takeoff. Testing under just such conditions is, therefore, crucial.

But night shipboard testing is revealed to have been less than realistic: only slightly more than half the rotorcraft that would normally operate off the deck of the *USS Bataan* were present during the testing, and "with more aircraft expected on board, there will be an adverse effect upon flight deck operations."[62] As indicated, serious and potentially dangerous aerodynamic issues come into play here, given prop wash from multiple MV-22s operating in close conditions on a dark and crowded flight deck, yet V-22 production was approved before testing under such conditions had even been attempted. This outcome is particularly disturbing coming four years after the GAO had soundly criticized NAVAIR's previous round of V-22 tests for lack of operational realism inherent in its "formation flight limitations—wingman shall avoid and not cross lead aircraft wake during formation flights, 250 ft. lateral and 50 ft. step-up separation shall be maintained."[63]

For "opposed landings" the testing site selected was at China Lake, where "limited electronic combat testing" was performed but the number and placement of antiaircraft gun and missile revetments was inadequate and "resulted in the inability to assess the effectiveness of tactical maneuvering approaches in a high-threat environment."[64] Not to mention standing orders limiting radical evasive maneuvers and forbidding vertical descent rates over 800 fpm (roughly 9.1 mph).

It seems that, in essence, approval has been given for groups of 24 Marines to fly into combat on MV-22s without the aircraft's required defensive weapon system and without knowing whether the V-22 will be able to employ tactical maneuvers to evade serious hostile

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61 Individual overwater personnel recovery tests performed more recently have relied on "Navy Search and Rescue swimmers as well as Navy SEALs and Air Force Pararescuemen" to assist the victim [James Darcy, V-22 PAO, email to author, June 20, 2006]. One wonders how the victim would have fared on his own, attempting to manage the hook or rescue litter in the maelstrom created by the V-22's violent downwash. Rescue team personnel wore masks and snorkels. The victim—bare-faced or mask-protected? The author's query to NAVAIR regarding this potential adjustment affecting the realism of such testing went unanswered over the three-week period preceding completion of this analysis.

62 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). V-*22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 7. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

63 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 27. Retrieved on Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.

64 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 7. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

threats. It is both inappropriate and dangerous to rely on recommendations that future testing cover many of these areas: such tests should have been conducted before this report could state "OT-IIG and live fire testing provides an adequate basis to determine the effectiveness, suitability, survivability, and safety of the V-22"[65]—and before full production approval. *After all, such determinations were the purpose of the testing before the granting of this approval.*

Is the V-22 meeting its goals?

How well does the V-22 meet operational requirements? The third section of the OT-IIG report describing the aircraft's operational effectiveness concludes that "The MV-22 Block A is operationally effective in medium-lift assault support missions in low and medium threat environments. VMX-22 accomplished all required missions within the test limitations encountered. … [T]he range for the MV-22 Block B [the *improved* model—author emphasis] carrying a 10,000-pound external load will fall approximately 42 percent short"[66] of the requirement. This embarrassing shortfall does not augur well, and "within the test limitations encountered" represents an attempt to rationalize other areas in which the aircraft did not fulfill intended requirements.

Although not performed during OT-IIG, the required transport of a production lightweight howitzer (known as the M777E1LW155 and weighing in at 9,980 pounds) had nevertheless been accomplished a year earlier on June 30, 2004, over a distance of 69 nautical miles, with a Block A V-22 depositing its load and returning to the ship without refueling. On the other hand, since the V-22 is unable to carry an up-armored Humvee on a single cargo hook, the OT-IIG external lift profile cited transport of a 6,250-pound water trailer and a 7,200-pound "operational combat vehicle"[67] later identified by the V-22 program's PAO as a standard—unarmored—Humvee. When standard Humvees proved extremely vulnerable in combat in Iraq, the acute need for up-armored versions quickly became apparent. *Now, more than three years later, certification of the V-22 to carry up-armored Humvees on two hooks has not yet occurred and* ***has not even been "identified as a requirement by the Marine Corps or prioritized in their funding of flight tests."***[68] (Depending on model and type, the up-armoring process—in the field or during manufacture—adds 1,000 to 2,000 pounds to a Humvee's weight.) Yet we are told that "this test event demonstrated the ability of a unit equipped with the MV-22 to conduct the critical ship-to-objective maneuver mission"[69]—albeit not with some of the tactical equipment likely to be most in demand.

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65 Ibid.
66 Ibid., 22.
67 Ibid., 10.
68 James Darcy (e-mail communication with author, June 19, 2006). Despite my often complex queries, some regarding perceived V-22 deficiencies, Darcy always presented the *Osprey* program in the most favorable light and did his best to obtain from the Integrated Test Team specific answers to my questions.
69 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 11. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

Even compartments in Table III-1 on page 15 of the OT-IIG report, "MV-22 Block A Performance Results," are filled with fudge: for Amphibious External Lift with a required 10,000-pound vehicle, a 6,900-pound vehicle is substituted, but the Block A *Projection* [author emphasis] suggests that a 10,000-pound vehicle therefore *ought to be able* to be carried 115 nautical miles (nm), even while another box admits that the improved Block B V-22 *can be projected* to carry said weight only 40 nm instead of the required 50 nm.

When it comes to mission planning, more problem areas emerge: computer limitations involving data entry into the Joint Mission Planning System (JMPS version 5.2) proved too cumbersome under tight time constraints (as in combat), not to mention the five-character limit for waypoint names and "limited available map-loading memory,"[70] possibly indicating a potentially obsolete computer system with limited hard drive space. Indeed, flight control computer obsolescence was a well known deficiency *more than three years ago*, with "component obsolescence," "PFCS processor throughput <20% reserve," and "Obsolete OP amp" all listed as "issues" in a *Tech Review* that spring.[71] Of the two planned ship-to-objective maneuver missions (one during daylight, the other at night), "the planned night mission did not occur."[72] Nor was this important test rescheduled—this despite the 2001 GAO report's clear criticism of NAVAIR for how its earlier "operational test waivers and limitations reduced testing for operational realism."[73]

Furthermore, in replicating a land assault troop-lift night mission, testers employed "a single aircraft using ballast instead of live troops."[74] Well, wars are not fought with ballast. And in the already congested troop bay of the MV-22 with its entangling seat belts and constrained space, just how would heavily laden combat-equipped troops have performed trying to exit the aircraft expeditiously in the dark under simulated fire in a hostile landing zone? Such potentially vital information was therefore not acquired before this aircraft was approved for production.

For the amphibious evacuation mission, more ballast was evacuated ahead of simulated invading forces. Aircraft flew day and night missions, one MV-22 with "4,400 lbs of ballast while the other carried 2,200 lbs. representing the weights of a recovery force and evacuated noncombatants."[75] Ballast, of course, does not get confused by strange crew chief embarkation orders given under stress of hostile forces about to enter the area, does not fumble with the

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70 Ibid., 9.

71 NAVAIR. (March 27, 2003). *Osprey* V-22: Tech Review, 83. Patuxent River, Md.

72 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 10. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

73 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 27. Retrieved on Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.

74 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation*, 11. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

75 Ibid., 14.

unworkable seat belts, does not get airsick during minor turbulence en route to the ship because lack of windows provides no visual horizon cues, does not face the problem of where to relieve oneself on a long flight where there are no what the troops label "piss tubes." Thus, realism was once again a casualty, and the opportunity to learn crucial lessons was sacrificed in the process.

Yet we are told that "during OT-IIG, the MV-22 Block A accomplished all required mission profiles."[76] For the required Self-Deployment Key Performance Parameter (KPP), the report documents no actual range flown test result, but instead lists the results that were "*extrapolated* to 2,660 nm [author emphasis] with one refuel using Block B auxiliary fuel tanks"[77]—the Block A Projection was then essentially left blank: "N/A" appears in the box. The Demonstrated Performance for Troop Seating box gives "24 Combat-loaded Marines"[78] when we have read about inert lumps of ballast. That's apparently all right: "*Projections* indicate that Block A aircraft *will* [author emphasis] meet all performance thresholds."[79]

Then why even proceed with the OT-IIG when NAVAIR can just present "projections"? Successful testing would have employed the *past* tense, stating that all performance thresholds *were* met, with all required mission profiles accomplished—without the need for scope clauses and hypothetical, unproven projections.

Is the V-22 ready for combat?

With deployment looming, this is a vital and important question. Unfortunately, even though the report's section on operational suitability professes that "OT-IIG demonstrated that the MV-22 Block A is operationally suitable,"[80] major problem areas make one question the logic and validity of this statement.

For example:

- According to the table on page 26, V-22 mission commanders should be prepared for false alarms after every 1.6 hours of flight, for an aircraft mission abort after the equivalent of eight three-hour flights, or a parts failure any time an aircraft has flown more than 90 minutes. (This table surprisingly purports to "provide sound evidence of the reliability maturation of the MV-22 aircraft."[81])

- Mission planners are to be prepared for an egregiously excessive post-abort mean repair time of nine hours before the rotorcraft will be ready for resumption of the mission—when "the MRTA threshold requirement for the Block A aircraft is 4.8 hours or less."[82] And that's not taking into account that "the individual component repair list classifies

76 Ibid., 15.
77 Ibid.
78 Ibid.
79 Ibid., 16.
80 Ibid., 36.
81 Ibid., 26.
82 Ibid., 27.

over 500 of more than 590 items as 'Repair Not Authorized at the I-Level.' Those items have to be returned to depot-level repair facilities when they fail."[83]

- Operating manuals remain in disarray: "Two important technical publications were missing,"[84] and "technical documentation related to structural repair procedures was not adequate;"[85] maintainers complained "regarding the lack of technical documentation related to the electronic wiring suite"[86]—despite the fact that *four years earlier*, the GAO had emphasized that the "NATOPS manual lacked adequate content, accuracy, and clarity," and that "V-22 technical documentation did not support the operation and maintenance of the V-22."[87] Worse, after years of development and flight testing, pilot manuals recommend helicopter-type autorotation to a safe landing as a procedure of choice following dual engine failure—even though this report concluded, "The V-22 *cannot* [author emphasis] autorotate to a safe landing."[88]
- "A complete assessment of the logistics support system is not possible because of the immaturity of that system"[89]—in this report written 16 years after first flight of the aircraft.
- "Damage to [the cabin wall] can make the aircraft unavailable for an extensive period"[90] because it cannot be repaired in the field. NAVAIR knew two years earlier that since "the cabin wall is load-bearing…[it] may not be repaired without first performing an engineering assessment…*not available at the combat unit level*."[91] The key recommendation in the report, "re-design of cabin wall,"[92] was not done. "Unfunded,"[93] the report noted. End of discussion. (The word "composites" does not appear in the entire OT-IIG Report—yet roughly 43 percent of the airframe[94] is constructed of composite materials that clearly pose critical maintenance problems when damaged because of their computerized stress-path configured lay-up during manufacture.)

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83 Ibid., 29.
84 Ibid., 36.
85 Ibid.
86 Ibid.
87 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 30. Retrieved on Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.
88 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 4. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.
89 Ibid., 29.
90 Ibid., 44.
91 NAVAIR. (March 27, 2003). *Osprey* V-22: *Tech Review*, 94. Patuxent River, Md., emphasis original.
92 Ibid., 97.
93 Ibid.
94 Osborn, Graeme. (Aug. 1, 2000). "Tilting." *Flight International*, 62. Last retrieved on Sept. 25, 2006, from Lexis-Nexis Academic.

- Once-standard equipment has to be custom-remanufactured because of the *Osprey*'s limitations. For example, consider the M151 Jeep[95] that the V-22 was theoretically designed to carry, and the Humvee, which it cannot carry internally (or even the up-armored version externally). The solution? A cut down version of the old M151, which (according to the Federation of American Scientists and others) already had "a tendency to tip over" and "didn't quite have the mobility, speed, or durability to get Marines into the environments they will need to be in during the 21st century."[96]

This compressed version is called the *American Growler*; its frame narrowed by 10 inches so it can fit into the *Osprey*—a step that, obviously, now renders it even more prone to rollover. Some Growlers will tow French-designed rifled 120 mm mortars, and others will pull ammo trailers or carry troops. It will take two *Osprey*s (at $70 million each) to deliver one mortar team 100 miles inland:[97] one for three Marines, a *Growler* (at more than $100,000 each) and its mortar; the second for three Marines, a second *Growler* (at another $100,000+), and an ammo trailer with 30 mortar rounds. If either MV-22 has to turn back—or gets shot down—the other MV-22 is rendered essentially useless and the mission a likely failure.

A few areas in operational suitability warrant a detailed discussion, including communications, shipboard compatibility, ergonomics, the personnel hoist and the defense weapons system.

COMMUNICATIONS. Despite the *Osprey*'s ostensible transoceanic self-deployment capability with air-to-air refueling, the Marine Corps' V-22 leadership failed to account for the need to meet International Civil Aviation Organization (ICAO) requirements specifically for high-frequency (HF) radio installation for beyond line-of-sight communication. NAVAIR's March 27, 2003, *Tech Review* states: "Current UHF/VHF and SATCOM capability cannot fulfill this function,"[98] and urges that they "convince HQMC to establish requirement."[99] Given the ICAO's well-known and long-standing requirement, this V-22 omission represents a significant oversight. Three years later, it remains uncorrected.

Furthermore, the OT-IIG report tells us that critical *Osprey* voice information exchange requirements (IERs) cannot be met when its radio system is operating in the anti-jam mode—a key expectation in combat, one would assume. Moreover, "user ID numbers greater than 399 causes the mission computer to cycle continuously, blanking out flight displays,"[100] a

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95 The M151 is no longer in service and has been out of production since 1978. In addition, it now seems that even the original M151 would have been too wide to fit into the V-22 since the new Growler must be narrowed by 10 inches.

96 Federation of American Scientists. Website entry entitled "M151 Jeep." Last retrieved on Oct. 2, 2006, from http://www.fas.org/man/dod-101/sys/land/m151.htm.

97 Neff, Joseph. (Jan. 8, 2006). "Experts Blast *Osprey* Buggy." *News & Observer*, A1. Neff and his extensive investigative reporting on the V-22 *Osprey* have been extremely helpful to this author.

98 NAVAIR. (March 27, 2003). *Osprey* V-22: *Tech Review,* 114. Patuxent River, Md.

99 Ibid., 118.

100 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 33. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

situation that could possibly lead to loss of the aircraft. It would therefore seem that the MV-22's Single Channel Ground and Airborne Radio System (SINCGARS) is essentially useless.

SHIPBOARD COMPATIBILITY. In the two years following key modifications to the MV-22's software and hardware, which included a second full round of testing and evaluation, problems still arose aboard ship. Once again, heat from the V-22's rotor/prop turbine exhaust caused the *USS Bataan*'s flight deck to buckle under the right engine following more than 20 minutes of idle; the same problem had occurred on both the *USS Wasp* and *USS Iwo Jima* during the previous round of testing. Since space limitations mandate that "any maintenance actions requiring the proprotors to be spread [out of their folded mode] must be conducted on the flight deck,"[101] both bad weather and flight operations would still delay such repairs. Furthermore, incompatibility of ship and aircraft power sources unnecessarily complicates logistical support: 118 volts on the *USS Bataan* vs. an MV-22 requirement (for its sensitive avionics system) of 115 (+/- 2) volts.

What about flight ops engulfed in unstable and unpredictable flight deck aerodynamics? This consideration was not mentioned in the report clearing the way to V-22 *Osprey* full-rate production, despite significant problems reported in the V-22 Ship Aeromechanics Brief.[102] On U.S. Navy amphibious assault ships, the flight deck is awash with four tricky turbulence fields generated around deck structures as the ship steams into the wind at more than 20 knots: gusts from unsteady over-bow separated flow, turbulent flow aft of the island, a "necklace" vortex around the base of the island, and rotor-height "wingtip" vortex curling inboard up over deck-edge spots.[103] Add to that, flight deck turbulence from multi-aircraft rotorwash during launch and recovery operations.

Three primary problem areas soon emerged: the unpredictability of controlling aircraft directional heading on or close to the deck under these varying aerodynamic influences—what NAVAIR labels Lateral Control Nonlinearities (LCN); sudden induced and unpredictable rolling movements by the aircraft—otherwise known as On-Deck Uncommanded Roll Oscillations (URO); and an unsettling tendency for the aircraft to roll unpredictably forward or backward—labeled Excessive On-Deck Roll Response to Upwind Aircraft (ERR). Of the three, LCN is best understood; URO and ERR are "not very well"[104] understood in that "we cannot predict conditions"[105] that cause them. What are the implications? These aeromechanic phenomena have already reduced shipboard combat tactics options[106] and "could lead to damage or injury."[107] Remember that OT-IIG testing failed to employ standard

101 Ibid., 32.
102 Long, Kurt. "V-22 Aeromechanics: Shipboard Compatibility Issues." NAVAIR 4.11, Patuxent River, Md. Received circa summer 2003, from Col. Harry Dunn.
103 Ibid., 4.
104 Ibid., 14.
105 Ibid.
106 Ibid.
107 Ibid.

full-deck complements of aircraft generating normal and far more challenging aerodynamic environments, and that it eliminated several planned shipboard test operations—so *Osprey* will enter service facing known dangerous shipboard aerodynamic conditions with no previous training in compensating for those conditions.

ERGONOMICS. The good news is that the "new cockpit door…is problem-free and easy to operate."[108] But it's downhill from there:

1) *Windows*. Windows are small and so poorly placed that "crew chiefs *still* [author emphasis] criticize the poor outside field of view,"[109] rendering them unable "to scan for traffic and airborne or ground threats."[110] Previous testing had revealed this critical deficiency years earlier, yet no design changes were implemented. This deficiency resulted largely from failure to build a full-scale working plywood or metal mockup of the cabin that would assess field of view, space for troops, placement of personnel hoist and defensive weapon more than 17 years previously. Now we are prepared to use an assault transport carrying troops into a hot landing zone—but unable to defend itself or even see where hostile fire is coming from or where it is clear to land. This sounds like a recipe for disaster.

Moreover, what will the effect be on troops being carried? Participants in tests observed:

- "Crew chief/observer will not be able to get visual on Bandits or SAMs due to poor porthole size,"[111] said one participant.
- "This was a very frustrating flight because of the crew chief's inability to provide the pilots with vital information regarding the aggressors' location,"[112] according to another.
- Two additional Marine test participants reported that "since there are no portholes to look out many people got airsick on the bird" and that "we also cannot see where we are going or which way we are oriented to the LZ [landing zone]."[113]

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108 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 33. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

109 Ibid., 33.

110 Ibid., 33-34.

111 The following pages will frequently include selections from 49,586 questionnaire responses from 499 V-22 OT-IIE testing participants. These were provided as electronic files forwarded to the author by Col. Harry Dunn, circa 2004, and in the footnote citations for each quotation will be listed as "Ram Responses" or various "Results" files— followed by the specific page number. Here, for example, [S-8 Results, 45]. To minimize reader distraction, minor spelling revisions have occasionally been made in these passages quoted from the original questionnaires.

112 E-1 Results, 44.

113 E-1 Results, 44.

Given this situation, just how has the MV-22 provided "increased battlefield situational awareness and reduced aircrew workload,"[114] as the Pentagon report asserts?

2) *Cabin*. Bell Textron spokesman Bob Leder said his best search efforts revealed that in the mid-1980s, a basic outline framing was constructed to evaluate routing of hydraulic lines and control cables, but that no record of a full-scale plywood or metal cabin mock-up and its subsequent ergonomic evaluation can be found.[115] Thus, before design was finalized and the first prototype flew, there had been no physical evaluation of troop and vehicle capacity, as well as such additional features as grab bars and relief outlets for use on long flights. This misjudgment is taking its toll since cabins currently cannot carry the jeep for which it was designed: the MV-22 has been in development so long that the M151 Jeep no longer exists. The newer up-armored Humvees are now both too large and too heavy to be carried internally or even externally by the MV-22. Furthermore, the "CCP-10618, Cargo Handling System *Redesign* [author emphasis], failed to improve underfloor structure floor structure [sic] for heavy wheeled vehicles."[116]

How did the troops react to this oversight? One commented that "loading and unloading cargo is very difficult because of the installation of the rail system, total junk! It's hard and time-consuming to install, it's poorly made and breaks on a regular basis."[117] (Note that this comment refers to the redesigned system.)

Other problems remain with the cabin structure of the V-22, including:

- an inability to be pressurized, so cruise altitude while carrying troops is limited to lower levels where the aircraft is more vulnerable to ground fire. The lack of pressurization also sacrifices range because denser airs leads to higher drag.
- inadequate cooling and heating systems that cannot anticipate both hot climates, with a need to keep cargo and troops in heavy combat gear cool, and cold climates, when long flights might necessitate extra heating. Troops arrive dehydrated and enervated by the heat, or chilled and stiff from the cold. *This concern was raised four years earlier in the previously cited GAO report:* "Cabin environment cannot be adequately controlled to prevent extreme temperature conditions."[118] Troops have also voiced complaints about the cabin temperatures. "I have a big concern about the temperature of the inside of the aircraft. You could have heat casualties before they even get on the ground,"

114 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 2. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

115 Leder, Bob. (Personal communication, April 28, 2006.)

116 NAVAIR. (March 27, 2003). *Osprey* V-22: *Tech Review*, 36. Patuxent River, Md.

117 S-9 Results, 42.

118 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 18. Last retrieved on Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.

reported one Marine.[119] Another declared: "ECS is designed to keep the cabin +10 degree ambient. On cold days with sub-zero wind-chill and temperature crewmembers are literally freezing. Hot days are the opposite extreme."[120]

- poorly designed seat belts with hard-to-manipulate latches that entangle easily. Unfortunately, this "may [read *will*] increase the time for embarkation and debarkation, posing a safety risk during combat or emergency evacuations."[121] The short seat pans cut circulation and "caused [troops'] legs to fall asleep during flight"[122] (not to mention the possible onset of potentially fatal deep vein thrombosis), because shock-attenuating pistons under the seats force troops to stow their combat packs on their laps (aggravating leg circulation problems) or in the aisle, causing congestion that "may [read *will*] impede an emergency or combat egress."[123]

Let the troops who participated in OpEval assess the V-22's combat readiness in regards to ergonomics: "The V-22 is too difficult to get in and out of in a hurry [with] all our gear on. Since there is no armament on the V-22, we are a sitting duck."[124]

"Onload of troops takes much too long…space is limited and maneuverability inside the bird is difficult. The longer the onload the more security of the bird is jeopardized in a combat situation."[125]

"The rear hatch on this helicopter has not in two flights dropped closer than two feet to the deck. This is unacceptable when considering a fatigued Marine with 60-90 lbs combat load."[126]

As one Marine observed, "If there are 24 troops with packs and weapons, the aircraft is too packed and EGRESS [sic] could be impossible for the troops. There is no room for the c/c [crew chief] to get to anyone to help them."[127]

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119 General Results OVR01, 4.

120 Ram Responses, 7.

121 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 34. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

122 Ibid.

123 Windows, seat belts, hoist, et al.—these should not be considered just minor technical issues: the Air Force's CV-22 version is designed specifically to work with Special Operation Force (SOF) units whose mission frequently involves quick behind the lines insertion or extraction of individual agents into or from hostile territory; the Navy will no doubt be called on to use V-22s to rescue pilots ditched at sea. Key missions for both services—missions in which speed can save lives and in which an automatic hoist can help counter the *Osprey*'s problematic gale-force downwash. For units performing vertical assaults into hot landing zones potentially covered by automatic weapons and rocket-propelled grenade (RPG) launchers, clear field of view ("situational awareness") for the crew chief guiding the pilot and quick egress by the assault squad are of paramount importance.
The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 34. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

124 E-1 Results, 36.

125 E-1 Results, 36.

126 S-9 Results, 42.

127 S-9 Results, 1.

In short, this rotorcraft is not properly configured to carry troops into combat, and when it does, it may cost them their lives.

PERSONNEL HOIST. The essential personnel hoist—another key piece of equipment required for several of the V-22's vital missions—was still uninstalled by the end of OT-IIG. The Joint Operational Requirements Document (JORD) lists a 600-pound capacity hoist with at least 235 feet of useable cable and a winch speed range from 0 to 225 fpm.[128] It was never included in the original design, and 17 years after the flight of the first prototype, it had still not been redesigned into the system or installed in test aircraft—*in an aircraft one of whose primary missions from the start has been search and rescue and covert insertion/retrieval of individuals or small groups of special forces personnel.*

INEXPLICABLE. Since the release of the September 2005 OT-IIG report, however, NAVAIR has tested a V-22 personnel hoist with the cable length and speed capabilities noted above, according to James Darcy, V-22 public affairs officer, in an email correspondence with the author on June 19, 2006. Its intended mounting above the open rear ramp will obviously pose challenges in terms of both the V-22's longitudinal center-of-gravity sensitivity and placement of the defensive gun that is theoretically scheduled to be mounted on that same ramp—the narrow ramp down which 24 combat-loaded Marines are also supposed to make their speedy assault egress.

DEFENSIVE WEAPON SYSTEM. Would CH-47 *Chinooks* have been tasked with carrying troops into dangerous landing zones in Afghanistan and Iraq stripped of their defensive machine guns? Of course not. Then why was the V-22 designed without a gun for suppression of enemy air and ground defenses (SEAD)? Seventeen years since the flight of the first prototype, it still has not been redesigned into the system or installed. One Marine's comments included: "little room for gear…no weapons system…this aircraft is not made for the infantry Marine."[129]

Not until September 2000 did Bell-Boeing announce that it had "selected the General Dynamics Armament Systems 12.7 mm. Turreted Gun System (TGS) for the U.S. Marine Corps MV-22 *Osprey* tiltrotor and will begin integration next year [2001]."[130] Five years later, we are still waiting. Based on the GAU-19/A Gatling gun already fitted to various U.S. helicopters, the three-barrel TGS would be able to fire up to 1,200 rounds per minute and weigh roughly 460 pounds empty, with a 750-round under-floor magazine. Together, the TGS would add even more weight at one extremity of a fuselage already plagued by longitudinal center-of-gravity issues resulting from engines placed at the wingtips. Bell-Boeing obviously felt it could work, and planned to mount it on the aircraft's forward 'antiplow' bulkhead, with a belt-feed through the nosewheel bay to the magazine that was to be reloaded via the

128 JORD Requirements, Feb. 15, 2001, revision, 20-21.

129 E-1 Results, 40.

130 Penney, Stewart. (Sept. 26, 2000). "Bell Boeing picks gun turret for MV-22 Tiltrotor." *Flight International*, 18. Last retrieved on Sept. 15, 2006, from Lexis-Nexis Academic.

forward cargo hold. However, within two years the program office "shelved plans to integrate the…gun turret under the chin due to cost."[131]

Recently there has been discussion of mounting a gun on the rear ramp, this time aggravating the center of gravity problem at the other end of the fuselage lever-arm. Such a mounting would, of course, present V-22 gunners with the interesting challenge of trying to suppress enemy defensive fire while backing blind into hostile landing zones. After landing, their egress blocked by the gun mount, assault troops on board would wait several minutes for the gun to be dismounted before pouring down the ramp to seize their objective. One can only question the judgment of the originator of this ramp-gun concept.

What will be the cost in Marine lives lost? Consider also the financial cost of additional resources now required in the form of armed escort aircraft to suppress enemy defenses prior to arrival at hot landing zones, plus a necessary training program in joint tactical multi-aircraft assault operations. Meanwhile, a combat rotorcraft carrying Marines into harm's way will do so with no viable method for defending the aircraft or the crew and troops on board against enemy ground defenses.

How can the Marines call this suitability for combat?

Pernicious problems remain

Earlier OT-IIE testing and the fatal crash of two V-22s in April and December 2000 had revealed serious and persistent issues involving flight control software reliability, the impact of downwash on operations, and vortex ring state. These and numerous quality control manufacturing deficiencies were addressed during the almost 18-month stand-down ordered by the blue-ribbon panel—and during early phases of OT-IIG OpEval testing following resumption of V-22 flight operations at the end of May 2002. Thought by NAVAIR and the Pentagon's OT-IIG report to have been "resolved," these three serious problems persist, plaguing the program and affecting flight and ground operations—as well as the safety of all Marines on board. If the MV-22 is ordered into combat next year, these ongoing issues could re-emerge with a potentially deadly effect.

FLIGHT CONTROL SOFTWARE. To evaluate flight control system (FCS) software and hardware, the OT-IIG report tells us that the "manufacturer integrated three *simulation* [author emphasis] laboratories. This triple tie-in lab allowed a pilot in a realistic cockpit simulator to fly mission profiles and perform emergency procedures using actual flight control system hardware and software."[132]

Remember the "ballast Marines" that were substituted for live troops in prior testing? In the software testing as well, we face non-realistic situations lacking actual flight test

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131 Lewis, Paul. (Nov. 12, 2002). "Interim solution found to V-22 gun turret expense concerns." *Flight International*, 4. Last retrieved on Sept. 25, 2006, from Lexis-Nexis Academic.

132 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 18. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

conditions that would include vibration, temperature variations, humidity and pressure fluctuations that come with actual engine operation and changes in altitude—to name a few. Furthermore, simulation parameters are defined by our limited understanding of the aerodynamics involved rather than by the real-world aerodynamics.

Meanwhile, according to reporter Bob Cox in the Feb. 24, 2004, *Star-Telegram*, in November 2003 problems arose when a V-22 "moved rapidly side to side when the computer controls tried to counter the pilot's commands, alternately increasing and decreasing power to the aircraft's twin rotors." Bell spokesperson Bob Leder admitted to Cox that "further refinements to the flight control software and hardware are necessary." It was also flawed flight control software that contributed significantly to the December 2000 crash that killed four Marines.

Now fast-forward to spring 2006. In Bob Cox's April 6, 2006, article for the *Star-Telegram,* on March 27 of that year, an *Osprey*'s electronic engine controls and flight control computer called for an increase in power and change in pitch angle of the prop blades as the aircraft perched on the hardstand, its engines idling. The V-22 lifted off vertically by itself—then crashed back to the ground, snapping off its right wing. The damage amounted to millions of dollars; the question of whether the aircraft can even be repaired was still pending three months later. The NAVAIR spokesperson told Cox that "an engineering investigation will look at computer software."

Then on April 11, 2006, *InsideDefense.com* reported that NAVAIR officials were looking into a "previously unpublicized incident in November 2005 that also involved an uncommanded engine acceleration."[133] That event occurred in flight while the V-22 was deployed on an amphibious ship. No accident occurred, no "root cause" was found. Col. Bill Taylor, V-22 program manager, downplayed that engine surge, claiming engine rpm are contained because "you have pitch on the blades already."[134] But if you are in combat and are on the borderline of vortex ring state or blade stall as you make a heavily loaded, maximum-rate vertical descent into a hot landing zone, an uncommanded power surge in one engine can potentially trigger blade stall and/or VRS, initiating sudden thrust reduction in that engine. This could potentially result in a rollover, loss of controlled flight, and a fatal inverted crash.

The flight control software issues are clearly not resolved.

IMPACT OF DOWNWASH ON OPERATIONS. Given the violent downwash from its powerful props, "the V-22 is capable of operating safely and routinely from unprepared landing zones consisting of grassy fields with some loose dirt," according to the OT-IIG report.[135] However, the V-22 may not be prepared to land on sand and loose stones common to the Iraqi desert and mountains of Afghanistan. These "grassy fields" may well be nonexistent at sites where the Air Force wishes to rapidly insert an SOF unit, or the Marines want to

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133 Castelli, Christopher J. (April 11, 2006). "November V-22 Incident Under Review." *InsideDefense.com*. Last retrieved on Sept. 27, 2006, from http://www.military.com/features/0,15240,93814,00.html.

134 Ibid.

135 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 19. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

land a squad to eliminate a pocket of insurgents. The OT-IIG report itself states that "in more severely degraded environments, such as in brownout conditions, the immediate area affected by downwash is large," and "approximately 25 percent of the landings in severe brownout conditions resulted in unintended wave-offs."[136] Realistically, then, there is at least a 25 percent chance troops will not get on the ground in what could be a crucial situation.

None of this should come as a surprise: four years earlier the 2001 GAO report had specifically voiced its concern that powerful V-22 rotor downwash "creates brownout and whiteout [if landing on snow] conditions, makes fast rope and rescue hoist operations hazardous, reduces effectiveness of combatants, [and] forces sand, snow, other matter into aircraft and into aircraft components."[137]

While the 2005 OT-IIG report's section on downwash claims that during fast roping "the ropers reported downwash under the rotor was manageable,"[138] for other Marines downwash impact bordered on devastating: "Rotor wash off the end of the ramp and behind the aircraft is horrendous…a person cannot see or breathe in that area…a survivor [awaiting pick-up from the water] would have a real problem under the aircraft," reported one staff sergeant following a water ops exercise.[139] In that regard, no at-sea individual victim pick-up was apparently attempted during OT-IIG. Indeed, the aircraft and its crew themselves face danger: one officer described how in "attempting to reach "10 and 10" (10 feet above the water at 10 knots ground speed) the pilot clearly lost visual contact with the water surface and plunged the belly of the aircraft into the water."[140] This does not bode well for the Navy's intended use of the V-22 for search and rescue at sea.

In ground operations, "the rotorwash actually knocked two Marines over on two different lifts," reported one observer.[141] Another said, "The prop wash made [it] extremely difficult to employ our weapons effectively."[142] Given the violent downwash problem, one Marine summarized the situation succinctly: "I think the V-22 is not a good aircraft for combat."[143]

Just how has the impact of downwash been 'resolved'—and what will be its effect in combat?

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136 Ibid., 19.

137 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 17. Last retrieved on Sept. 26, 2006, on http://www.gao.gov/new.items/d01369r.pdf.

138 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 20. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

139 General Results, 4.

140 Anonymous. (Dec. 12, 2003). *Lingering Safety Concerns over V-22.* Last retrieved on Sept. 27, 2006, from http://www.g2mil.com/V-22safety.htm. Both this website and retired Marine officer Carlton Meyer, its originator, have been extremely helpful to this author.

141 E-1 Results, 40.

142 E-1 Results, 43.

143 E-1 Results, 75.

Deployment looms: will *Osprey* and its occupants survive in combat?

The Pentagon's report assures us that "MV-22 Block A is a survivable aircraft in low and medium threat environments"[144]—even though it is still missing the *required* defensive weapon "needed to suppress threats while approaching a landing zone, disembarking troops within the landing zone, and during egress from the landing zone."[145] Frankly, this situation does not enhance "survivability."

While the MV-22 will attempt to avoid known high-threat areas, some will remain unknown until too late. And, as we have discovered, ambushes occur, and even low- and medium-threat situations often escalate rapidly into high-threat situations. Weapons against which the aircraft was tested in lower threat areas included: assault rifles, 7.62 mm and .50 cal/12.5 mm rounds, SA-7 type shoulder-launched missiles. Ironically, it seems not to have been tested against the rocket-propelled grenade (RPG), one of the most ubiquitous projectiles encountered in combat in Iraq. Moreover, the current reports do not reveal the general results when the weapons concerned were fired at the fuselage and wings or at the engines, prop blades, or windshield, or nexus points where hydraulic lines or avionics are grouped together—even though specific effects may need to remain classified. If at the fuselage, the aircraft may well have survived with holes in the skin, but would troops in the cargo bay have taken severe casualties? No mention is made of any interior Kevlar shielding for the troops.

Clearly, threat avoidance will be a key priority for V-22s embarking on their missions. In that process they will be assisted by the *Osprey*'s reduced acoustic signature and its IR suppression system, which will delay its ability to be heard and will provide some protection against heat-seeking missiles. Along with its various radar and laser warning systems, these are encouraging. Nevertheless, the countermeasures dispensing system was found to have insufficient capacity for longer missions, and radar reflection from the V-22's total propeller disc area of more than 2,267 square feet rivals that of two Boeing 707s in formation.[146] (Given that situation, one can only wonder at the logic behind the development of top-secret "stealth paint" for the fuselage at a cost of $7,500 per gallon; *the one aircraft they painted required 10 gallons for a paint job costing $75,000*—but those huge, whirling discs were still there, bouncing back radar signals with gusto.)

More problematic is the APR-39(V)2 radar detector set, which compromises survivability because it does not provide enough space to display "all threats contained in the system's threat

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144 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 43. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

145 Ibid., 42.

146 Anonymous. (Dec. 12, 2003). *Lingering Safety Concerns over V-22.* Last retrieved on Sept. 27, 2006, from http://www.g2mil.com/V-22safety.htm. Col. Harry P. Dunn, USAF (Ret.), is quoted in the text. This author is most grateful for Dunn's generosity in sharing both his extensive V-22 files and his decades of rotorcraft expertise.

assessment report;"[147] also note that "a separate threat display makes it difficult to correlate displayed threat information with aircraft position presented on the cockpit map display."[148] Furthermore, "the synthetic warning voice provided by the APR-39 is unintelligible to all crew members."[149] In brief, confusion may reign in the cockpit as the aircraft approaches a hot landing zone and the pilot has to look back and forth between different screens to locate the threats, even as the recorded voice warning about those threats is providing meaningless and distracting information, and while main cabin windows' "limited visibility…prevents the crew chief from providing effective lookout against surface and airborne threats."[150]

Along with assistance from such sensors, the V-22's ability to delay converting from airplane mode is touted as allowing it to "maximize airspeed, and therefore minimize exposure time when landing in hostile zones."[151] However, this is not necessarily the case. It may minimize *transit* time, but actual "landing in hostile zones" requires conversion to helicopter mode during the last and most vulnerable part of the journey. And the report acknowledges that while in that mode, the MV-22 might well face an environment that changes suddenly from low- or medium-threat to high-threat, a situation in which helicopters would employ jinks and tight, banking turns at minimum altitude. But during OpEval testing, "the MV-22 generally did not employ rapid tight turns while the nacelle angle was greater than 60 degrees."[152] No comment was made about the stresses and bending moments imposed by such maneuvers endangering the structural integrity of both the rotor blade system and the complex, multi-jointed cross-wing interconnecting shaft system that provides potential emergency power linkage between the two engines. No comment either on the fact that such rapid tight turns or high-speed descent in helo mode could put the *Osprey* in danger of encountering blade stall and/or VRS, which below 1,600 feet could result in a sudden roll and a fatal crash.

Aware of such maneuvering often required in the stress of combat, in late 2002 one military observer specifically recommended adding to V-22 testing three specific evasive maneuvers that included "maximum rate course reversals and landing zone aborts." This should have been nothing new; as he formally cited, such maneuvers had long been an integral part of accepted and official rotorcraft doctrine—"consistent with the definition of 'aggressive agility' as required for utility rotorcraft in ADS-33E, Performance Specification, handling Qualities Requirements for Military Rotorcraft, 21 Mar 2000."[153] NAVAIR agreed that these maneuvers should be tested, but they still had not done so more than a year later

147 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 41. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

148 Ibid.

149 Ibid.

150 Ibid., 42.

151 Ibid., 16.

152 Ibid.

153 Anonymous. (Dec. 12, 2003). *Lingering Safety Concerns over V-22.* Last retrieved on Sept. 27, 2006, from http://www.g2mil.com/V-22safety.htm.

"because the V-22 rotor control system repeatedly exceeded rotor disk flapping limits[154] *while approaching the requested conditions."*[155] As V-22 Red-Ribbon Panel Coordinator Col. Harry Dunn explained, "Whereas virtually *all* helicopter rotors have a limit of 28 to 30 degree blade flapping capability, the V-22 propellers are limited to 10 degrees to avoid damage to the rotor, rotor swash plates, and rotor hubs…[E]xceeding these limits can result in rotor failure or breakage, leading to aircraft control failures."[156]

Indeed, one such maneuvering attempt narrowly averted disaster on March 3, 2003. Aircraft #10 was executing a 60-degree bank and pullout of the kind that might be required while entering a defended landing zone. Rotor blade and hub flapping limits were exceeded; severe blade/rotor hub vibration and irregular thrust pulses ensued.[157] The pilot managed to land safely, but the damage had been done: in the subsequent maintenance check, all leading edge fairing brackets for the prop blades had to be checked for cracks; after the engine nacelles were opened up, it was found that a right-hand swash plate had to be replaced; the 12 left-hand and right-hand bond straps had been cracked; an important left-hand component clamp was broken; a right-hand internal support bracket was found snapped; and a bolt head had been sheared off, with one photo revealing ricochet impact damage from this sheared bolt head.[158]

One can perhaps see why defensive maneuvering was not tested—especially with assault troops on board. Now contrast the V-22's lifting and maneuvering 'capabilities' with those of the CH-53A *Sea Stallion*, an early version of one of the helicopters the V-22 is replacing: almost 40 years ago and eight months after setting an unofficial 28,500-pound payload record for non-Soviet production helicopters, on Oct. 23, 1968, "the *Sea Stallion* performed a series of rolls and loops"[159]—air show maneuvers V-22 pilots would be forbidden even to attempt.

Following inbound defensive maneuvers, what if one engine malfunctions or is damaged by enemy fire? Such an event should not pose a problem: the OT-IIG report reassures us that since "an interconnecting cross-shaft allows either engine to power both rotors…the V-22 can

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154 Blade flapping: By necessity equipped with hybrid propeller/rotor blades, the V-22's propulsive system is more mechanically complex than that of either an aircraft or a helicopter. Acceleration in horizontal flight is dependent on the variable pitch capability of its constant speed props, whose individual pitch angle can be changed to increase or diminish thrust. But rather than to the thicker, rigid shaft typical of standard turboprops, this prop/rotor blade system is attached to its shaft by a floating, gimbaled ring assembly that behaves like the teetering rotorhead employed by many smaller helicopters. Therefore, when the V-22 is in helicopter flight mode, this same proprotor assembly now needs to be able to relieve maneuvering or gust stresses to the rotor hub/prop shaft by 'flapping'—bending up (or down) from its plane of rotation by a maximum of no more than 10 degrees. The V-22's flapping limit of 10 degrees is only one-third that of a normal helicopter, and its shaft/spinner/rotor head must not exceed that limit or the shaft can be bumped and damaged, leading to failure of the entire rotor system and loss of the aircraft and its occupants.

155 Ibid.

156 Anonymous. (Dec. 12, 2003). *Lingering Safety Concerns over V-22.* Last retrieved on Sept. 27, 2006, from http://www.g2mil.com/V-22safety.htm Dunn, quoted in text.

157 Col. Harry P. Dunn (personal communication, July 15, 2004).

158 Col. Harry P. Dunn (personal communication, July 31, 2004).

159 Willis, David. (August 2004). "Lifting the Load: Heavylift Helicopters." *Air International*, 64.

take off and land *vertically* [author emphasis] with only one engine operable."[160] Although a V-22 program spokesperson told me that its testing regimen has included a number of one engine inoperative (OEI) transitions in level flight and in steeply angled descents to roll-on landings (and equivalent rolling short takeoffs),[16144] it is disturbing to note that *during its 17 years of evaluation, the V-22 has never been tested in this purely vertical OEI landing or takeoff mode with one engine completely shut down*, exactly the kind of landing or takeoff necessary from a small clearing in a jungle or on a mountainside. Since this key test was omitted, the report's claim cannot be considered seriously. Furthermore, because any OEI situation will immediately deprive the aircraft of 50 percent of its previous max power capability, and given that the V-22's prop design does not permit a helicopter-type pre-landing flare, vertical landing of a loaded OEI *Osprey* would result in substantial landing impact with probable damage to the aircraft.

In such a case, the aircraft's inerted fuel tanks will help prevent explosions. The V-22's energy-attenuating seats also seem to be a good idea, although their pistons block combat pack stowage and promote congestion in the aisle. In addition, the landing gear is apparently "designed to allow crew and passengers to survive a vertical, 24 feet-per-second sink-rate landing, provided the main landing gear is down."[162] On the other hand, 24 feet per second (fps) translates into 1,440 fpm, which vastly exceeds the MV-22 800 fpm (13.3 fps) descent rate limitation imposed to avoid VRS or blade stall! One wonders at the robustness of that landing gear when the March 27, 2003, Tech Review cited concerns that "NLG [nose landing gear] may not be capable of hitting a 1.4 in. bump," and that in 14 years of flight (at that time) and after various tests, "aircraft has not completed 2 in. and 4 in. bump test to simulate potholes or obstacles on a hypothetical rough field."[163] The fact that a combat aircraft that is supposed to be able to make rough field landings and takeoffs had not by that time completed tests for obstacles of 1.4 inches, 2 inches, 4 inches is absurd.

It gets worse. The Tech Review also stated "MLG [main landing gear] brake disks [were] damaged structurally during 0.2G [sic] brake deceleration tests."[164] No wonder "NASA Langley review indicated neither NLG nor MLG would pass requirement."[165] That such basic and serious structural issues should have been plaguing an assault transport at that late stage of its development is baffling.

What would happen if, through fuel contamination or battle damage, both engines were lost? On Sept. 24, 2002, about four months after the MV-22 had resumed flight testing, and

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160 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 1. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

161 James Darcy (V-22 program PAO), email to author, April 24, 2006.

162 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 43. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

163 NAVAIR. (March 27, 2003). *Osprey* V-22: *Tech Review*, 59. Patuxent River, Md.

164 Ibid., 182.

165 Ibid., 59.

after the evaluating blue-ribbon panel approved the changes that were made following its fourth crash, V-22 program officials gave a presentation in Washington, D.C., at a luncheon for the Reserve Officer's Association of the United States, entitled: "The V-22 Tiltroter [sic]: Exemplar of Transformation—or its next casualty?" Prepared from a tape-recording, the transcript of that presentation records Col. Daniel Schultz of the U.S. Marine Corps, the V-22 Program Manager at the time, as saying, "The V-22, if it loses both engines,…has the ability to auto-rotate"—to an implied, presumably safe, landing.[166] Indeed, the 2005 OT-IIG report itself says in reference to "emergency landing profiles following sudden dual-engine failure" that: "dependent on altitude, the aircraft flight manual directs conversions to airplane mode or autorotation."[167] Yet this report's own executive summary states: "Emergency landing after the sudden failure of both engines in the Conversion/Vertical Take-Off and Landing modes below 1,600 feet altitude are not likely to be survivable. … The V-22 *cannot* [author emphasis] autorotate to a safe landing."[168] A subsequent comment in the summary states: "Additional flight tests should be conducted to provide validated procedures for dual-engine failure."[169] Any volunteers? Clearly, safe engine-out landing is a *major* unresolved issue for the V-22.

None of this bodes well for safety and "survivability."

As cited earlier, even more astounding is that more than four years prior to release of the Pentagon's September 2005 OT-IIG report, the GAO had sent to high Defense Department and Pentagon officials its own assessment of the V-22 program. In it they revealed that prior to OT-IIG, "developmental testing was deleted, deferred, or simulated in order to meet cost and schedule goals" and that the aircraft "is susceptible to sudden loss of controlled flight under certain conditions."[170] They found that "the effects of maneuvering limitations imposed to avoid the vortex ring state danger area…may limit the maneuver capability and hence the effectiveness of the MV-22 in some operational scenarios."[171] GAO cited a judge advocate general (JAG) report: "Given the rigors of combat, real world operations, and realistic training for both, the consequences of exceeding this particular envelope appears [sic] to be excessively grave (departure from controlled flight with no warning)."[172] Other deficiencies listed were: nonexistent autorotation survivability, an inadequate cargo handling system, and

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166 Center for Security Policy. (Sept. 24, 2002). *The V-22 Tiltroter* [sic]: *Exemplar of Transformation or Its Next Casualty?* Transcript from symposium held at the Reserve Officer's Association of the United States. Last retrieved on Sept. 28, 2006, from http://www.centerforsecuritypolicy.org/index.jsp?section=static&page=v22symposium.

167 The Pentagon, Office of Operational Test and Evaluation, Office of the Director. (September 2005). *V-22 Osprey Program: Report on Operational and Live Fire Test and Evaluation,* 35. Last retrieved on Sept. 27, 2006, from http://pogo.org/m/dp/dp-V22-dote-092005.pdf.

168 Ibid., 4.

169 Ibid., 35.

170 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 2. Retrieved from Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.

171 Ibid., 32.

172 Ibid., 28.

inadequate cockpit/cabin nuclear, biological, and chemical overpressure protection—despite Bell Helicopter Textron's ongoing claim that "the V-22 was designed to be fully mission capable in an NBC [nuclear, biological or chemical] contaminated environment."[173]

Both the incisive 2001 GAO report and 49,586 questionnaire responses from those previous 499 V-22 OT-IIE testing participants were ignored.[174] So, *more than four years later*, we read in the Pentagon's report *that those same problems—as well as others discussed above—continue to affect the program*. They have not been addressed—or solved.

Indeed, the contradictions emerging from the *Pentagon's own report endorsing the V-22 and clearing the way for its full-rate production approval* stand as clear evidence why—after a quarter century of design, development, and testing—full production should not have been approved. As one Marine put it, "I don't know why the Marine Corps didn't look more into this bird, testing wise, before buying so many."[175]

A time of reckoning

We must ask why this aircraft was approved for production when ongoing deficiencies will keep it from performing its mission and pose real dangers to those it will carry into combat.

Unfortunately, the serious issues discussed above seem irrelevant when one considers the irreconcilable and potentially fatal aerodynamic design conundrum posed by the high-twist propellers specially designed to power the V-22 in both horizontal and vertical flight.

When the *Osprey* goes into combat next year in Iraq, it will be subject to mandatory flight restrictions imposed on no other aircraft or helicopters. Intended to prevent both crippling rotor system damage and potentially catastrophic consequences of unpredictable and sudden onset of blade stall and/or vortex ring state, these restrictions will severely limit the V-22's evasive maneuvering ability and its vertical descent speed. The result, as described in *Defense News* in 2003, is a deadly Catch 22: if the V-22 cannot perform radical evasive maneuvers and if it descends so slowly into a heavily defended landing zone, it can easily be shot out of the sky. If it descends too quickly, blade stall and/or VRS can cause it to flip and crash, possibly killing all on board.[176] Furthermore, during a vertical assault landing in close formation with other V-22s and their turbulent wakes and violent downwash, these hazards will be intensified in an unpredictable fashion.

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173 Josten, Norb. (February 2001). "V-22 shines in simulated force protection scenario." *Bell Boeing Tiltrotor Team's Osprey Facts*, 12(2), 3. Last retrieved on Sept. 28, 2006, from http://www.boeing.com/rotorcraft/military/v22/tilttimes/feb01.pdf.

Five years later, the same astounding claim is being made on the airforce-technology.com website: the V-22's "*cabin* [author emphasis] and the cockpit are NBC (nuclear, biological and chemical warfare) protected with a positive pressure filtered air system." See Airforce-technology.com. U.S. AIR FORCE. (June 2, 2006). *V-22 Osprey Medium-Lift, Multi-Mission, Tilt-Rotor Aircraft,* 1. Last retrieved on Sept. 28, 2006, from http://www.airforce-technology.com/projects/*Osprey*. One asks how this can be possible when the cabin, as seen above, cannot even be pressurized sufficiently to carry troops above 10,000 feet.

174 Col. Harry P. Dunn (personal communication to Gen. Michael Hagee, CMC, Aug. 25, 2003).

175 S-9 Results, 36.

176 Gaillard, Lee. (July 7, 2003). "*Osprey*'s Fatal Flaw: Despite Upgrades, Tiltrotor is Vulnerable in Combat." *Defense News*, 29.

Solutions

For the V-22 in combat, there are no solutions, easy or otherwise.

So what should DOD do now? Rumsfeld, along with Navy, Air Force, and the Marine Corps leaders most closely involved with the V-22's development and testing, should all re-read the GAO and OT-IIG OpEval reports issued to, or in some cases by, them. Indeed, they should have read in late 2000 the Marine Corps' published findings of omitted testing in its own investigation into the April 8, 2000, crash in Arizona; again in early 2001 they should have read how the Integrated Test Team and OT-IIE OpEval planners had "deleted significant testing that would have provided additional knowledge on V-22 flying qualities and susceptibility to Vortex Ring State"[177]—testing that might have helped prevent the deaths of 19 Marines. These deficiencies, waivers, omitted testing, and dangerous and potentially fatal anomalies outlined above are therefore not new revelations.

Under those circumstances, the painfully obvious recommendation is that the V-22 not be deployed in combat. **If it is, and if Marines then die as a result of such flight restrictions or design and equipment deficiencies, the leaders should be held accountable. They did not insist on remediation or cancellation of a weapons system that they knew, or clearly should have known, posed inherently fatal hazards to its users above and beyond dangers normally expected in combat.**

And for the Navy and Air Force, a strong recommendation would be that—once sizable contract cancellation fees have been paid—they use remaining V-22 funding to purchase modern, in-production helicopters of the kinds listed below. (During high-speed vertical descent, all are safer and more survivable than the V-22; all three have cruise speeds roughly equivalent to each other.)

- AgustaWestland's US101 (EH-101): three engines, single rotor; recently selected as the U.S. presidential transport helicopter under licensed assembly arrangements with Lockheed Martin as prime contractor; capacity of 30 combat-equipped troops (more than *Osprey*);
- Boeing's CH-47F *Chinook*: two engines, two rotors; able to carry 33 combat-equipped troops (more than *Osprey*), and currently in production; and
- Sikorsky's H-92 *Superhawk*: two engines, single rotor; 22 combat-equipped troop capacity.

But, beguiled by initial performance promises and despite developmental deficiencies, the U.S. Marine Corps has remained loyal to its original and very expensive choice of the V-22 *Osprey*. Today, decades later, for the Corps there is no greater assault transport need—

177 United States of America Government Accountability Office. (Feb. 20, 2001). Report to Secretary of Defense Rumsfeld, Defense Acquisitions: Readiness of the Marine Corps' V-22 Aircraft for Full-Rate Production. GAO-01-369R, 11. Retrieved from Sept. 26, 2006, from http://www.gao.gov/new.items/d01369r.pdf.

whatever the platform. And for all three services, there seemed initially to be no greater promise than the V-22.

Since service needs and missions vary, their helicopter choices may well differ. But for the Marine Corps, the magic number seems to be 24—24 combat-equipped troops. Given that requirement and their need for long range, a refueling probe for self-deployment capability, and stated requirements for a defensive weapon and a rescue hoist, the US101 might seem to have the edge.

No matter what the services' choice, given V-22 maintenance problems and abort rates cited in the OT-IIG report, fewer, though slightly slower, helicopters might actually be required to perform any given mission. In transit, any of the three listed might take slightly longer to fly from ship to objectives beyond the beachhead, but during descent into heavily defended landing zones they would all be far less vulnerable, able to descend more rapidly and take radical evasive maneuvers that are not an option for the V-22. *And, of course, if fuel contamination or enemy fire cause total engine failure, all could autorotate and flare to a survivable landing—an impossibility in the V-22.* What would the cost be? A fraction of the V-22's, depending on the number ordered and equipment installed.

The choice seems clear.

Indeed, following that fourth crash when the death toll reached 30 in December 2000, the *Osprey* program should have been cancelled and the three interested services told to use remaining V-22 funding to purchase the currently in-production helicopter that would best suit their missions.

But as a former Pentagon director of operational test and evaluation so rightly points out, "By the time these problems are acknowledged, the political penalties in enforcing any major restructuring of a program, much less its cancellation, are too painful to bear. Unless someone is willing to stand up and point out the emperor has no clothes, the U.S. military will continue to hemorrhage taxpayer dollars and critical years while acquiring equipment that falls short of meeting the needs of troops in the field."[178]

Have we learned anything after 25 years, $18 billion, and 30 deaths? It seems not. But if we act quickly, we may still save lives.

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178 Christie, Thomas. (February 2006). "What Has 35 Years of Acquisition Reform Accomplished?" *U.S. Naval Institute Proceedings, 35.* Last retrieved on Sept. 22, 2006, from http://www.cdi.org/pdfs/Christie%20in%20Proceedings.pdf.

APPENDIX

Additional V-22 blade-twist implications for VRS

With the *Osprey*'s high-twist (47 degrees) blade, airfoil angle changes along the blade may lead to "local lift coefficients [that] may become large enough for the inboard sections of the rotor to stall."[179] This inboard stall generates cascading consequences that affect airflow through the rotor, strength of vortices trailing off the rotor tips, and the breakdown mode of the prop's powerful wake—creating conditions ripe for VRS. In a word, crucial smoothness and stability of airflow rapidly start to disintegrate in different ways and in all affected regions.

But the difficulty of *reliably* predicting the onset of VRS is further complicated (despite protestations to the contrary by NAVAIR) by the fact that "the onset of the VRS may be triggered by BVI [Blade Vortex Interaction] at the rotor *or by atmospheric turbulence* [author emphasis] rather than by larger-scale disturbances in the surrounding flow."[180]

Thus, it becomes a highly unpredictable realm that can also trigger dangerous engine power pulses: at moderate descent rates, rotors with highly twisted blades encounter "intense thrust fluctuations [up to 15 percent of the mean thrust of the rotor]…almost as soon as the rotor begins to descend."[181] When the frequency and power of these fluctuations are plotted on a graph, the steep rise of that slope "supports the idea that the onset of VRS is not gradual, but is associated with *catastrophic*, or at least a very sudden, *loss of stability in the rotor wake*" (author emphasis).[182]

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179 Brown, R.E., Leishman, J.G., Newman S.J., and Perry, F.J. (2002). *Blade Twist Effects on Rotor Behaviour in the Vortex Ring State.* Presented at the European Rotorcraft Forum, Bristol, England, Sept. 17-20, 2002, 3. Last retrieved on Sept. 27, 2006, from http://www.enae.umd.edu/AGRC/Aero/ERF_2002.pdf.

180 Ibid., 6.

181 Ibid., 7.

182 Ibid., 8.

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