Why the ARLEIGH BURKEs Handle Differently

The recent article "*A New Twist for Arleigh Burkes*" by Commander Terry Mosher highlighted again that handling the ARLEIGH BURKE destroyers is different from previous gas turbine propelled cruisers and destroyers. While it may appear that the DDG51 class should have similar performance to the other twin shaft, controllable pitch propeller, gas turbine ships, there are significant differences beyond the difference in length and hull form. While Commanding Officers have learned how to maneuver the ARLEIGH BURKE class, an examination of the cause and impact of these differences may be useful as observations for development of future ship control systems.

There are two major drivers, plus some contributing factors, that have led to the different handling characteristics:

1. The DDG51 ship class was optimized for anti-submarine warfare (ASW), incorporating the observations from the SPRUANCE class destroyer.
2. The control system specifications precluded using any feedback to keep the propulsion plant within safe operational limits.

A contributing factor was that those directly involved with determining the design of the control system primarily had fleet experience with steam powered ships, not gas turbine. Other factors, not examined here, include the difference in hull form, propulsion plant arrangement, and available shaft horsepower.

The principal design driver for ASW is keeping the ship quiet, reducing own-ship radiated noise that masks the submarine signature or enables counter-detection. The DD963 design maintains a minimum of 55 shaft revolutions per minute. Ship control at this RPM is provided by controlling propeller pitch, decreasing from 100 percent to zero percent. However, a propeller operating off design pitch generates significant additional noise. This was dramatically confirmed during early DDG51 trials. Two viewports were installed above the port propeller. In clear Caribbean waters, cavitation could be visually confirmed the instant the propeller pitch decreased below 100 percent. Also, when the DDG963s reached 100 percent pitch, they had significant speed, increasing hull flow noise and requiring an increase in masker air flow. This design did not provide optimum slow speed, quiet ASW performance.

The solution for DDG51 was to keep the gas turbine at idle until the propellers reached 100 percent pitch. This enables a much-slower quiet speed than the DDG963 design, but has several unintended consequences for ship control. First, as the turbines remain at idle, there is less immediate power to effect a change in ordered speed at these low power settings. Second, because the turbines remain at idle until 100 percent pitch, shaft speed decreases from a stop bell to the 100 percent pitch setting. This enables confusion, as a Sailor might only focus on RPM while setting the throttles in response to an order, resulting in the wrong speed. Next, there is different idle power available in split plant (single turbine online per shaft) and full power (dual turbine per shaft) modes. This means that performance is different depending on the plant mode—the ship reaches 100 percent pitch at one speed in split plant and a different speed in full power. Finally, there are some pitch settings that are not obtainable, especially in split plant mode where pitch rapidly increases to 100 percent with minor throttle adjustments. While this has no operational impact (the difference between 85 and 86 percent is negligible) it adds to the potential confusion factor. (See sidebar on *New Twist…* for additional details of DDG51 throttle modes.)

The DDG51 ship specifications required that the control system not rely on feedback to keep the plant within safe operational limits. This was interpreted by the design team to imply that shaft RPM feedback could not be used to control shaft RPM. Therefore, the control system implemented a purely predictive algorithm to control the gas turbine throttle and propeller pitch settings. The primary inputs to this were current and historical throttle position, outside temperature, and number of engines on-line. (There was a long-term control loop, but it was slow acting and had minimal authority.) This decision was made despite the fact that each shaft had six independent, redundant methods to measure shaft speed to keep the plant within limits (two tachometers on the reduction gear and two power turbine speed pickups per gas turbine). Reportedly, the industry designer had repeatedly told the program office this design would not work. The design worked as the designer had predicted. It was arbitrary and unpredictable. The Conning Officer had no idea what would happen when he gave a throttle order, except that it probably would not be the same response as previous. Worst case was a high-speed ahead bell to back 1/3. This action produced consistently hilarious results, unless you were either the Conning

Officer in a critical situation or the Engineer Officer that had to explain resulting performance to the Commanding Officer.

As we came to understand the problems with the throttle control, the Battle Group Commander eventually decided that immediate action was required, and tied ARLEIGH BURKE to the pier until the program office provided a new throttle control system. The interim solution was to implement the SPRUANCE-style system, with a fixed 55 SRPM minimum speed. My memory is that the "bells mode" pushbutton was converted to a 55 RPM, or "Shaft Idle" mode button. While we debated keeping the Shaft Idle mode in favor of the bells mode for maneuvering, the submarine was still quite a threat. There was concern that a ship would prefer this mode, even for ASW operations, precluding the quiet slow speed performance. After a series of data-collection trials, the control system was modified to include RPM feedback to control shaft speed and to increase throttle authority, so gas turbine power would be applied more rapidly as pitch increased. The essential element of the system, rapidly getting to 100 percent pitch for quiet operation, was maintained. We returned the Shaft Idle button to its original "bells mode" function. Finally, we made the RPM order indication blank below 100 percent pitch to reduce (but not eliminate) the RPM ambiguity. While we spent much effort in the trials trying to develop "balanced" twists, the final design did not completely achieve this goal.

This throttle control system has three different tables. There is one for trail shaft, one for split plant, and one for full power. Above 100 percent pitch at full power, the split plant and full power tables are identical.

The control system lead designers had significant steam experience. They had developed a method to simplify commands, especially where the pitch and RPM settings differed from split plant to full power. The programmed control lever (PCL) is calibrated from –3.3 to +10.0. A numeric setting was designed to produce the same speed in split plant and full power. In theory, ship speed was a specific integer multiple of the PCL setting. The Conning Officer could order "All engines ahead plus 2.0" and always get the exact same speed. No lookup table was required. This method of engine orders was never understood, and never took hold. It did not work in trail shaft mode. Depending on specific ship speed trials and system calibrations, ship speed might vary from this fixed integer multiple. In usual practice, the Conning Officer either gives a speed order, which requires the Lee Helm to refer to a pitch and RPM table to set the throttles, or provides the pitch and

RPM order directly. There may be a DDG51 class that uses the PCL numbers, but they are probably the exception.

So what did this design provide? First and foremost, the ultimate goal of absolute quiet ASW performance was maintained. However, unintended consequences included a system with potential confusion in translating speed orders to pitch and RPM commands at low speeds, differing slow speed performance depending on plant mode, and unbalanced twisting performance for standard orders. Commanding Officers have learned that a 1/3 twist has little authority, to add throttle quickly when quick response is needed at slow speed (and to remove that order quickly), and to work with the unbalanced standard twists.

What are the observations for future ship classes?

1. Predictable throttle response for maneuvering is critical. While there is a desire to minimize confusion to the Sailor, there may be a need for different control modes, such as one that is optimized for quiet slow speed ASW and one that is optimized with the required response for maneuvering.

2. When a designer with significant experience states a design is unworkable, he or she may be correct.

3. The real proof of a throttle control system is in ship performance at sea. The design should not be frozen until the system is proven at sea and unintended features removed. If it depends on a different method of commands, this must be carefully considered prior to implementation.