

Robust Adaptive Control for the Joint Direct Attack Munition

Control theory has been the enabling technology in achieving man's dominance over flight. Early experimental aircraft were difficult to control, had limited flight envelopes and flight times, and the pilots had to exercise control over the aircraft's trajectory using mechanical systems. In these early aircraft, the pilots had to adapt to changing environmental conditions and/or failures of any aircraft components. Over several decades, propulsion systems matured, our understanding of flight dynamics and aerodynamics grew, and computers and digital fly-by-wire systems were developed, all of which have helped bring automation to flight control.

With recent advances in control theory, particularly in the area of robust and adaptive control, fully automatic flight is now possible even for high-performance air systems. Among the first application successes of this new technology has been its technical transition to guided munitions, in particular, the Joint Direct Attack Munition (JDAM) system.



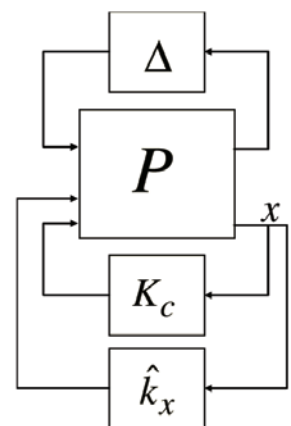
Robust Adaptive Control

Two techniques have been developed by control engineers and scientists to accommodate uncertainty in our knowledge of the system we are trying to control. The two techniques are complementary and have been combined to create robust adaptive controllers.

Robust control: Based on a mathematical model of the uncertainty, a formal design procedure is used to develop closed-loop controllers that will provide optimized performance and ensure stability over the range of uncertainty.

Adaptive control: Instead of developing a fixed controller over a space of model uncertainty, adaptive control adjusts the controller online based on detections of plant deviations from a reference model. Adaptive control augments and further extends the performance and robustness of the flight control system.

Shown at right is a control engineer's block-diagram representation of robust adaptive control. The nominal plant model P of the system under control (such as a missile) is subject to uncertainties Δ . The baseline flight controller K_c , designed using robust control techniques, is augmented with an adaptive controller. The state vector x is the input to both the baseline and adaptive controllers. The combination provides robust stability and performance over a substantially enhanced space of modeling uncertainties and can accommodate changes in the system under control.



JDAM

The Joint Direct Attack Munition is a guidance kit that converts unguided bombs into all-weather "smart" munitions. JDAM-equipped bombs are guided by an integrated inertial guidance system coupled to a global positioning system (GPS) receiver, giving them a published range of up to 15 nautical miles (28 km). The guidance system was developed jointly by the United States Air Force and the United States Navy. The JDAM was meant to improve upon laser-guided bomb and imaging infrared technology, which can be hindered by potentially bad ground and weather conditions.



Improving Weapon Control and Effectiveness

The U.S. Air Force Office of Scientific Research (AFOSR) sponsored researchers at The Boeing Company to develop and transition new robust adaptive control algorithms for application in the Joint Direct Attack Munition. The first transition has been to the 500-lb MK-82 JDAM.

Affordability and weapon accuracy (including collateral damage minimization) are among the primary objectives for the JDAM. The new robust adaptive control algorithms provide accurate control of the weapon, accommodating warhead aerodynamic uncertainties and off-nominal mass properties. Without control modifications, these uncertainties can significantly degrade weapon accuracy.

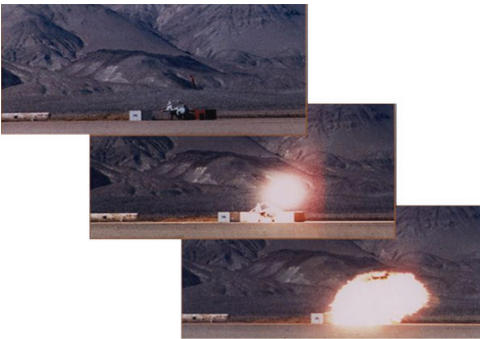
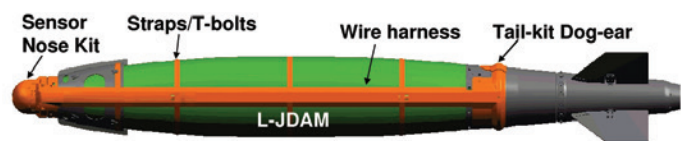


Photo sequence showing JDAM test against mobile ground targets

Other Applications

Other air systems are also prime candidates for robust adaptive control technology. Recently, another variation of the JDAM system has been developed and transitioned into production: a new dual-mode laser-guided JDAM system (L-JDAM) for detecting and prosecuting laser-designated targets (moving or fixed). For the L-JDAM development, the adaptive controller augments the baseline flight control system and only engages if the weapon begins to deviate from nominal behavior. This augmentation approach allowed The Boeing Company to develop and test the new laser variant without expensive wind tunnel testing, reducing development costs and schedule. The hardware modifications to create the L-JDAM weapon included the addition of a sensor nose kit (the sensor fit into the existing fuse well), wire harnesses, straps with barrel nuts, and symmetric tail kit dog ears where the sensor wire harness enters into the tail kit.



Laser-guided MK-82 scores direct hit against a moving target during tests at Eglin AFB.



Affordable hit-to-kill accuracy minimizes collateral damage; the photograph shows the hole made in the target by a (nonexplosive) weapon.