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THE DEVELOPMENT OF THE ANGLED-DECK AIRCRAFT CARRIER

Innovation and Adaptation

Thomas C. Hone, Norman Friedman, and Mark D. Mandeles

In late 2006, Andrew Marshall, the Director of the Office of Net Assessment in the Office of the Secretary of Defense, asked us to answer several questions: Why had the Royal Navy (RN) developed the angled flight deck, steam catapult, and optical landing aid before the U.S. Navy (USN) did? Why had the USN not devel-

oped these innovations, which “transformed carrier design and made practical the wholesale use of high-performance jet aircraft,” in parallel with the RN?¹ Once developed by the RN, how had these three innovations “jumped the gap” to the USN?

The detailed answers to these questions are in a study (*Innovation in Carrier Aviation*) that we submitted to Mr. Marshall.² In the present article we summarize the relevant, complex history contained in that study and draw some inferences about innovation from our findings.

THE PROBLEM

In the winter of 1944–45, a committee of senior officers of the Royal Navy decided that in the future most carrier aircraft would be jets and that the design of carriers would have to be modified to “fit” the following characteristics of early jet aircraft:

- Jets landed at higher speeds than piston-engine aircraft. In fact, to have optimal control, the pilot

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would have to land with “power on” instead of killing his engine when the landing signal officer gave the “cut.”

- Jets accelerated slower than piston-engine planes on takeoff. They would need to be catapulted off the carrier’s deck.
- Early jet turbine engines consumed more fuel than piston engines, which meant that it was important to find ways to keep the jets in the air as long as possible, especially if jet fighters were to serve as the force’s combat air patrol.³

The committee that had defined the problems of operating jet aircraft from carriers turned to the Royal Navy’s technical experts at the Royal Aircraft Establishment (RAE) at Farnborough, England, for detailed methods of solving those problems.

In 1938, the RAE had created its Catapult Section, a branch of its larger Main Drawing Office. The Catapult Section was composed of skilled engineers, technicians, and “draughtsmen” who specialized in designing and testing catapults and arresting gear for Royal Navy carriers. This “ground crew” was assisted by experienced test pilots. In April 1945, the Catapult Section was renamed the Naval Aircraft Department. Its head was a civilian engineer named Lewis Boddington. He was already deeply involved in the task of finding a way to create a new kind of carrier for jet aircraft.⁴

On 7 June 1945, the Naval Aircraft Department submitted a “Proposed Programme of Experimental Work” to the head of the RAE. The goal of this effort was to test the feasibility of using jets without undercarriages on aircraft carriers. There were four stages to the department’s plan. Stage 1 was a detailed program of experiments with models. During stage 1, a special concrete pit, two hundred feet by seventy feet, would be built at Farnborough in order to test a pneumatic deck. In stage 2, dummy aircraft (Hotspur gliders) would be dropped on and towed across a temporary “flexible deck.” At the same time, the engineers at the RAE would be designing a full-scale deck for use at sea.

In stage 3, actual jet aircraft would test the flexible, or pneumatic, deck at Farnborough. Their tests would determine the proper procedures for landing a fighter without landing gear on a “flexdeck.” Stage 4 would consist of tests at sea. By then the RAE hoped to have “a mechanical sighting instrument which will convey to the pilot by an automatic ‘batsman’ or by a relayed signal . . . the approach he is making and indicate the correction, if any.”⁵

By June 1945, then, Boddington and his colleagues had identified two solutions to the problems outlined by senior Royal Navy officers the previous winter—a new form of landing deck and an improved means of guiding pilots of jets onto that deck. Boddington followed the 7 June proposal with a paper dated 17

July arguing that “the large increase in take-off speed which will result from the developments in the [jet] aircraft . . . , and the resulting necessity to remove the present free-deck take-off restrictions will demand assisted take-off under all conditions.”⁶

There they were: a modified landing deck, a landing aid to assist pilots, and “assisted take-off under all conditions.” These three ideas would make the modern aircraft carrier possible. They were “on the table,” so to speak, in the summer of 1945. It would take ten years to go from this remarkable insight to the first really modern carrier, USS *Forrestal*.

ADAPTATION VS. INNOVATION

What about the USN? Were its carrier aviation specialists doing the same kind of thinking and planning as their counterparts in the RN? The answer is yes and no. At the end of 1944, for example, Vice Admiral Marc Mitscher, who had commanded Task Force 38 at the battles in and around the Philippines in October of that year, recommended to the staff of the Chief of Naval Operations (CNO) that an informal board consider developing an aircraft carrier design that would take account of the lessons learned during the major carrier operations of that year. His recommendation was seconded by the “type commander” of Navy air forces in the Pacific.⁷

The head of the Aviation Military Characteristics branch in the office of the Deputy Chief of Naval Operations (Air)—known as DCNO(Air)—Captain William T. Rassieur, accordingly studied the actual and potential impacts of new and heavier aircraft on the existing *Essex* class and on the larger *Midway*-class carriers then under construction. Rassieur’s analysis considered the carrier air group and the carrier as a single system. His argument was that the purpose of this system was to generate sorties. To do that optimally, the carrier needed multiple catapults that could operate simultaneously. In addition, the carrier’s aircraft elevators would need to be located at the edges of the flight deck in order to free up deck space for aircraft waiting their turns at the multiple catapults.⁸

By the end of June 1945, Captain Rassieur had submitted his analysis to the board that had been created on the basis of Vice Admiral Mitscher’s recommendation. Early in July, the members of that board endorsed the concept of a carrier with “a radically redesigned flight deck and a new mode of operations.”⁹ In parallel with the deliberations taking place in the office of DCNO(Air), engineers in the Navy’s Bureau of Aeronautics (BuAer) studied the potential of turboprop-driven aircraft on carriers. Their work led the chief of BuAer, Rear Admiral Harold B. Sallada, to propose to the CNO in December 1945 that the Navy develop and procure carrier-based bombers that could carry very heavy bomb loads.¹⁰

The new DCNO(Air) was Vice Admiral Mitscher. He endorsed Sallada's recommendation, as did the CNO, Admiral Chester Nimitz. In February 1946 the Vice Chief of Naval Operations, Admiral (and aviator) DeWitt Ramsey, directed the Navy's Bureau of Ships (BuShips) to initiate a new carrier design study. As Norman Friedman discovered, BuShips had a new preliminary design (termed "C-2") ready in April.¹¹

However, there was also another carrier concept under development in 1946. C-2 was a modification of the *Midway* design; its primary purpose was to carry and launch very large bombers. But the Bureau of Ships was also working on a new fleet carrier—a general-purpose carrier (CVB-X) to succeed the World War II *Essex* type.¹² CVB-X, which eventually became the ill-fated *United States* (canceled by the Secretary of Defense in 1949), was also designed to carry large bombers, for both nuclear and conventional missions.

The interest in nuclear attack inside the Navy was strong. BuAer produced an "outline specification" for what became the AJ Savage carrier bomber in January 1946.¹³ Private firms were requested to respond to the specification, and senior military officers and civilians within BuAer met in March of that year to decide whether the plane could be developed.¹⁴ The Aircraft Laboratory of the Naval Air Materiel Center (NAMC) was already developing preliminary bomber designs and gathering information on land-based bomber designs being considered by the Army Air Forces.¹⁵

In June 1946, Rear Admiral Jerauld Wright, the Deputy Chief of Naval Operations (Plans & Policy), had argued to the CNO, Nimitz, that the existence of nuclear weapons—even the large and heavy plutonium bomb used against Nagasaki in August 1945—justified building large, long-range carrier bombers and carriers to support them.¹⁶ In July, the acting Secretary of the Navy, John L. Sullivan, wrote to President Harry Truman that the "high mobility of the Naval Carrier Task Force combined with its capacity for making successive and continuous strikes in almost any part of the world make this force a most valuable means of waging atomic bomb warfare."¹⁷ As retired Vice Admiral Jerry Miller was to put it in 2001, the nuclear mission became the "only game in town" after World War II.¹⁸

Very quickly, the U.S. Navy went in a different direction from the Royal Navy. For the RN, the focus in 1945 and 1946 was on rethinking the design and flight-deck operations of an aircraft carrier to fit the characteristics of jet aircraft designed for the mission of convoy protection. The RN did not envisage a nuclear strike role for its carrier aircraft. The USN, by contrast, focused on heavy attack and then on nuclear strike—operations emphasizing new and larger aircraft on new and larger carriers. Unlike the RN, the USN had to prove that it

could play as an equal with a land-based air force (what would become in 1947 the U.S. Air Force) in the mission of nuclear strike.

But this meant that the U.S. Navy wanted to *adapt* carriers and carrier aircraft to a new mission, while the Royal Navy wanted to overcome the problems (higher landing speeds, the reduced responsiveness of turbojet engines, etc.) that made it almost impossible safely to operate jet aircraft on existing carriers at all. The RN's technical specialists at Farnborough understood that they had to innovate. The USN also had to innovate, but in a very different way and at a different level. It had to show that a relatively heavy bomber, weighing over sixty thousand pounds, could be launched from a carrier.¹⁹ Making that happen was the primary mission of the U.S. Navy's carrier aircraft community after mid-1946.

THE RN AND THE USN GO IN DIFFERENT DIRECTIONS

In 1946, the engineers and technicians at Farnborough were actively developing and testing their prototype flexdeck, or cushioned carrier landing deck. The flexdeck was actually "an interim measure which, if used with existing jet designs with their undercarriages removed, would teach us a lot and show the way to the solution" of the problem of creating a new type of carrier. That, at least, was the view of Rear Admiral M. S. Slattery, the RN's Chief of Naval Research, in April 1945.²⁰

After extensive tests of developmental models of flexible landing surfaces, the staff at Farnborough began working on a full-scale system in January 1946. As anticipated, some major problems developed. The "cushion" for the flexible deck was composed of a series of inflated, sausage-shaped flexible cylinders. On top of the cylinders was a flat rubber deck—the "carpet"—along which the landing aircraft was to skid. Tests with modified gliders dropped onto such a surface showed that a method had to be found to keep the weight of the landing aircraft from pushing one inflated cylinder over its neighbors and thereby reducing dramatically the cushion effect.²¹

The real problem confronting the ground crew at Farnborough, however, turned out to be the carpet itself. As one of the engineers observed, "nothing of this magnitude had been attempted before, [and] a great deal of experimental work with the manufacturers [was] necessary before the design could be finalized."²² Beginning in March 1947, the engineers and technicians at Farnborough began testing a flexible deck two hundred feet long and sixty wide, complete with its own arresting gear cable. The first manned landing was made on 29 December 1947 by the noted RN test pilot Eric Brown, and it nearly cost him his life.²³ He was fortunate not to be seriously injured or killed.

Tests continued in 1948, and Brown made “forty of these landings in all” at Farnborough.²⁴ Then the flexible deck was installed aboard carrier HMS *Warrior*, and Brown put a Vampire down on it for the first time on 3 November 1948. After a long string of successful landings, Brown argued in his report of the trials on *Warrior* “that the principle of flexible deck landing for undercarriageless aircraft is fundamentally sound. . . . It may even be that future swept-back and delta plan form aircraft will be forced to adopt this method of landing on carriers, since all calculations point to serious wheeled landing problems on such aircraft.”²⁵

Brown was puzzled that other navies did not perceive the utility of the flexdeck. He knew that the U.S. Navy’s Bureau of Aeronautics had watched the progress of the RN’s work, and he knew that engineers in BuAer were interested in it.²⁶ What he may not have known about, however, was the opposition to the flexdeck by BuAer’s chief, Rear Admiral Alfred M. Pride.²⁷ Once Pride left BuAer and became the aviation type commander for West Coast aircraft in May 1951, the engineers in BuAer who thought that the flexdeck might have potential got the green light to develop a version for the U.S. Navy.²⁸ Though that version was eventually tested, the USN never adopted the flexdeck, mostly for the same reasons that the RN did not make it standard.²⁹

In fact, for convoy protection the USN developed vertical-takeoff-and-landing aircraft—aircraft that convoy escorts could carry. BuAer issued a request for proposals to industry for such aircraft in 1948 and tested two unique experimental models in 1954–55.³⁰ Neither had the performance required.

In effect, the RN’s technical experts worked on how to create an innovative carrier/jet combination after World War II. The work of their American counterparts was overshadowed by the U.S. Navy’s effort to develop carrier aircraft that could carry the large nuclear weapon then in existence. The Bureau of Aeronautics ordered the AJ-1 Savage—“the smallest plane which can carry the atomic bomb”—from North American Aviation in June 1946.³¹ The Savage was a piston-engine aircraft with a turbojet engine in its tail. At a loaded weight of over fifty-two thousand pounds, it was significantly heavier, as well as somewhat larger, than the North American PBJ-1H twin-engine bomber that was launched from and then recovered aboard USS *Shangri-La* (CV 38) in November 1944.³² In November 1946, the Chief of Naval Operations “directed the DCNO (Logistics) to modify the three CVBs [*Midway*-class carriers] to permit the operation of AJ Savages carrying atomic bombs.”³³

This, then, was the pattern of USN development: first, develop the AJ-1 and design a successor jet-only bomber (the A3D Skywarrior); simultaneously, modify the three *Midways* so they could operate the AJ-1; and third, design a new carrier built expressly for an aircraft with the weight and performance

characteristics of the A3D. In the meantime, to make it clear to senior officials in the administration of President Harry Truman that the Navy could operate nuclear-armed bombers from its carriers, demonstration flights would be launched from *Midway*-class carriers using long-range P2V-3C Neptunes, each weighing over seventy thousand pounds. All this was an audacious effort—nothing less than a gamble. Over a period of less than five years, the AJ-1 Savage was pushed prematurely into operations, the Bureau of Ships spent many man-years on the design of a “super” carrier, BuAer solicited bids for what became the A3D, and Navy pilots flew their P2V-3Cs off *Midway* and its two sisters.³⁴

THE RN AND THE U.S. NAVY COME BACK TOGETHER

This series of events was very different from what was happening at RAE Farnborough. The flexdeck, though demonstrated successfully at sea, had proved not to be the solution to the challenge of merging jet aircraft with carriers. The basic problem was that the flexdeck left very little room to line up aircraft at the forward end of a carrier’s flight deck to await their turns at the forward catapult. As Captain Dennis Cambell, an experienced naval aviator then serving as the Deputy Chief RN Representative at the Ministry of Supply, would recall, the “difficulties [with the flexdeck] were insurmountable.” On 7 August 1951 he chaired a meeting of naval officers and technical experts to determine whether the RN could design a carrier capable of operating aircraft with or without undercarriages.³⁵ Lewis Boddington was one of the attendees.

The result of this meeting—where Cambell first presented his idea of an angled flight deck—and of some thinking by Boddington afterward was a flight deck angled enough to port so that any landing aircraft that did not successfully engage the arresting gear wires could accelerate, take to the air again, and rejoin the landing “pattern” to make another attempt.³⁶ In the meantime, Rear Admiral Pride, as chief of BuAer, had already directed the Naval Air Test Center (NATC) in Patuxent River, Maryland, to study means of making jet landings on carriers safer.³⁷ As we have already noted, Pride had refused to support the flexdeck concept, but he quickly embraced the concept of the angled flight deck—an idea that BuAer had considered in the 1930s for a combination cruiser/small-carrier design.³⁸

Sources differ on just how the angled-deck concept jumped the gap between the Royal and U.S. navies. Contacts between Royal Navy and U.S. Navy aviation officers during World War II were very strong, and the RN continued to assign liaison officers to BuAer after the war.³⁹ British technical specialists also stayed close to their American contemporaries. For example, the U.S. Navy provided the RN in November 1948 a full set of deck plans for the eventually canceled carrier *United States* (CVA 58) and detailed drawings of carrier *Midway* (CV 41),

along with information regarding the development of arresting gear suited to the larger carrier aircraft then being developed.⁴⁰

In his memoir, Captain (later Rear Admiral) Cambell notes that he mentioned the angled-deck concept to a delegation of U.S. Navy officers in September 1951. As he recalls, “they said very little, but . . . they exchanged significant looks. A few weeks later we heard . . . that the USN were already planning to angle the flight deck of the carrier *Midway*, for a preliminary trial.”⁴¹ In his *Wings on My Sleeve*, test pilot Eric Brown noted that he had been directed by his superiors to take “with me details of a new idea to revolutionize carrier-deck landing” when he joined the U.S. Navy’s test pilots at the NATC in late summer 1951.⁴² Harold Buell, who commanded Fighter Squadron 84 on *Antietam* (CV 36) in early 1953, later remembered that Brown’s espousal of the angled deck did not immediately gain support at the NATC, because Brown “was talking of only a four-degree deck angle, which would drastically limit the number of aircraft on a carrier deck during flight operations. . . . However, the idea sparked further thinking, and when the angle was increased to eight degrees . . . , it was decided to test the concept further.”⁴³

Preliminary tests in the spring of 1952 with an angled deck painted on *Midway*’s axial flight deck were so promising that the U.S. Navy began converting *Antietam* to an angled-deck configuration in late summer that same year. In January 1953, tests at sea on *Antietam* were successful, and Carrier Air Group 8 spent just over two months learning how to use the new deck configuration during exercises off Guantanamo Bay, Cuba. As then-Lieutenant Commander Buell observed, “To an experienced tailhooker, landing a jet airplane on an angled deck was sheer bliss.”⁴⁴

It’s important to note here that the experiments with the angled deck paralleled the introduction of the steam catapult into the U.S. Navy. After World War II, BuAer invested in three basic catapult types: improved versions of existing hydraulic catapults; an electrically driven design; and a slotted-cylinder, expanding-gas type that had been pioneered by German engineers during the war. An improved hydraulic catapult designated H-8 was installed on modernized *Essex*-class carriers, and it satisfactorily launched the first jets. But the hydraulic approach seemed to be nearing the limit of its effectiveness.⁴⁵ BuAer was developing heavier and heavier aircraft, such as the AJ Savage and what would become the A3D Skywarrior. In January 1949, therefore, Rear Admiral Pride reached the conclusion that slotted-cylinder, explosive-gas catapults would eventually replace the existing hydraulic equipment.⁴⁶

The slotted-cylinder catapult was a long tube with a nearly full-length slot in its upper surface. A piston could be driven under pressure at high speed down the length of the tube. Fitted to the piston was a hook extending upward through

the slot, and the hook was attached to a bridle that could be connected to an airplane on the flight deck. Two problems faced the designers of slotted-cylinder catapults. The first was safely generating the expanding gas that would drive the piston down the cylinder at the proper rate of acceleration. The second was sealing the slot behind the piston as the piston traveled. The catapult developers working under the Bureau of Aeronautics could not solve these problems.⁴⁷

BuAer's catapult developers knew about the Royal Navy's work on a steam catapult, but they ranked it third in importance, after their own explosive-driven and hydraulic models.⁴⁸ But by 1951 the Royal Navy was successfully launching aircraft from an experimental steam catapult built on top of the flight deck of the ex-carrier HMS *Perseus*. Rear Admiral Apollo Soucek, then the senior U.S. Navy aviator in the U.S. embassy in London, recommended that the U.S. Navy pay the cost of having *Perseus* demonstrate its steam catapult in the United States.⁴⁹ The Chief of Naval Operations approved the proposal, and *Perseus* arrived at the Philadelphia Naval Shipyard in January 1952.

The tests of the RN's steam catapult, performed while *Perseus* was tied up in the shipyard, were a signal success, but BuAer's Captain Sheldon W. Brown, head of the Ships Installations Division, was concerned that the installation on *Perseus* would not withstand the greater steam pressures used by U.S. Navy carriers.⁵⁰ In Philadelphia, and later at tests at Norfolk, Virginia, *Perseus*'s catapult used steam at a pressure of 350 pounds per square inch (psi). Brown warned that the steam catapult might not perform well with the 600 psi steam provided by the American propulsion plants. As it turned out, Brown's fears were not justified.⁵¹

By the spring of 1952, senior aviation officers in the U.S. Navy were convinced that the RN's steam catapult would work on their ships and would accelerate their heavy attack aircraft to flight speed. A year later, as we have seen, the angled deck had proved itself operationally. The next step for the U.S. Navy was to install both innovations in existing carriers and in carriers under construction, such as the new carrier *Forrestal* (CV 59). In the meantime, the RN was developing the mirror landing system that was to make possible the optical glide slope for landing on carriers.

In the summer of 1951, Lieutenant Commander Hilary "Nick" Goodhart, working under Captain Cambell, devised an ingenious method for guiding jet aircraft at the proper angle onto an angled flight deck. The idea was to use a light source at the stern of the carrier to project a "ball" of light into a stabilized mirror located next to the angled landing deck and angled at three degrees to the vertical. If the pilot, coming in to land, kept the ball right in the middle of the mirror, the plane would descend at the correct angle for a safe landing. Cambell endorsed the idea, and the technical staff at Farnborough, some of whom had been working on a radar-guided landing aid for some time, developed a

prototype device and tested it successfully in March 1952.⁵² An improved version of the prototype went to sea on carrier *Illustrious* in October.

In 1953, Lieutenant Commander (later Vice Admiral) Donald D. Engen, a USN exchange officer at the RN's Empire Test Pilots School at Farnborough, tested the optical landing aid at Farnborough and then at sea, on *Illustrious*. Engen recognized the value of the system and how it would complement the angled deck. He enthusiastically endorsed the RN's equipment and operations in reports to the Office of the Chief of Naval Operations and the NATC.⁵³ As a result, BuAer had an optical landing aid fully operational on *Bennington* (CV 20) in the summer of 1955.

Because it had more funds, the USN was able to combine the three innovations—angled deck, steam catapult, and optical landing aid—in a new carrier (*Forrestal*) before the RN could complete its new *Ark Royal*. *Forrestal* had been designed as an axial-deck carrier. Approved in the fall of 1950 for inclusion in the fiscal year 1952 shipbuilding program, *Forrestal* “was commissioned on 1 October 1955, despite having been redesigned (with an angled deck and steam catapults) during the course of construction.”⁵⁴

LESSONS LEARNED

It is always risky to draw lessons from a single case, because there is no guarantee that any future case will resemble closely enough the one under study. Nevertheless, we believe that some useful lessons can be gleaned from the research that we did for the Office of Net Assessment. We will cover these lessons as we answer the questions that were posed to us by Andrew Marshall.

Why did the Royal Navy develop workable catapults, the concept of the angled deck, and an effective optical landing aid before the U.S. Navy did? There is no one answer to this question. However, what is striking in this instance is the accuracy with which the RN's officers and technical specialists initially defined the problems posed by the adoption of jet aircraft. As we showed in our earlier study, *American & British Aircraft Carrier Development*, the RN's carrier arm had fallen behind its competitors in the U.S. and Japanese navies before World War II.⁵⁵ By the summer of 1945, a majority of aircraft on British carriers operating in the Pacific were American designs, and RN carriers were using what the USN called the “deck park” as an integral element of flight-deck operations.⁵⁶

But the RN had a wartime staff-committee system that could and did recover from the errors made prewar, and the officers involved realized in the winter of 1944–45 that jet aircraft posed a series of interrelated problems for existing carriers. The RAE engineers at Farnborough defined those problems in quantitative terms and systematically analyzed potential solutions to them. The result was,

first, the flexdeck concept and then a series of experiments to demonstrate that the prototype flexdeck would actually work.

A complement to the flexdeck was a slotted-tube catapult designed to launch the jets without undercarriages. It was tested successfully at Farnborough in November 1953, but by then it had already been superseded by a steam-powered slotted-tube design that had been patented by Colin Mitchell in 1938.⁵⁷

Fortuitously, everything came together for the RN in the summer and fall of 1951. The flexdeck was dropped in favor of the angled deck. The steam catapult proved itself reliable and effective in launching aircraft with landing gear. Commander Goodhart's concept of an optical (or mirror) landing aid turned out to be efficacious.

Where was the U.S. Navy while all this was going on? Its senior aviation officers were preoccupied with three issues: first, demonstrating that Navy carrier aircraft could carry nuclear weapons; second, defending naval aviation in the acrimonious dispute with (after the summer of 1947) the U.S. Air Force over service roles and missions; and third, developing reliable and powerful turbojet engines.⁵⁸ The larger Navy was also going through a series of major internal changes, including experiments with nuclear power and missiles, plans for deploying two major fleets (one each to the western Pacific and the Mediterranean), and adapting its staff structure in Washington, D.C., to a new pattern of national-security decision making.⁵⁹

In effect, the U.S. Navy's leaders were distracted. They also suffered from the effects of a change made to the organization of OPNAV, the Office of the Chief of Naval Operations, during World War II: in 1943, the Secretary of the Navy had created a deputy Chief of Naval Operations for aviation. This decision centralized policy making for naval aviation inside OPNAV, but the senior officers there were, as we have noted, preoccupied with a range of demanding issues after 1945. What they therefore wanted from the Bureau of Aeronautics was aircraft that could carry nuclear weapons, facilities on the *Midway*-class carriers for the storage and assembly of nuclear weapons, and one or more new carriers to get the new heavy bombers within striking range of the Soviet Union. In a sense, the OPNAV officers were revolutionaries. They wanted to give the Navy's carriers a new role, a strategic role, but they also aimed only to *adapt* the existing concept of the aircraft carrier to a new family of heavy bombers.

For their part, the U.S. Navy's catapult designers believed that their planned innovations—especially the replacement of hydraulic catapults with new gas-powered, slotted-tube designs—would work, but they did not. In addition, the most pressing problem for the NAMC's engineers in the two years after World War II was developing a new barrier that could safely stop jets that had

missed arresting gear wires as they landed.⁶⁰ The NAMC's engineers were struggling to adapt existing equipment and concepts to carrier aviation. Their counterparts at Farnborough, by contrast, began their postwar studies with an innovative mind-set and kept it. Consequently, it took aviator Rear Admiral Soucek to convince two successive chiefs of naval operations to bring the steam catapult to the United States for trials. The success of those trials convinced the CNO, then Admiral William Fechteler, to force the Bureau of Aeronautics to adopt it.

It was not sheer stubbornness that kept the U.S. Navy's catapult engineers from embracing the steam catapult. They simply did not think it would work with the high-pressure, high-temperature steam produced by the boilers of the U.S. Navy's carriers. Only the success of the trials with HMS *Perseus* compelled BuAer's specialists to change their minds, and even then they believed that their own designs would eventually prove superior to the RN's steam catapult.

Their resistance to the steam catapult is a sign that the consensus reached in the RN in 1945 regarding the new relationship between jet aircraft and carriers took longer to develop within the U.S. Navy. For example, the Bureau of Ships was saying in 1953 that "the transition from propeller to jet propulsion . . . has . . . thrown the design of aircraft carriers into a transition stage. Some of the results of this transition, canted decks and steam catapults, are, of course, already with us. Another change less apparent, but still fundamental, is the shift in the aeronautical factor that exerts the predominant influence on the size of aircraft carriers."⁶¹ What this sort of thinking shows, in our view, is that the USN's technical specialists were slower to grasp the nature of the jet-carrier relationship than their RN counterparts.

That is one major reason why the U.S. Navy did not develop the angled deck, steam catapult, and optical landing aid in parallel with the British. American aviators did recognize the need for deck-edge aircraft elevators, as Captain Rassieur's 1945 analysis shows, and the British picked up on this idea. However, OPNAV, BuAer, and BuShips lacked the shared understanding that placing jets on carriers meant that the carriers had to change in a fundamental way.

Put another way, there was no one forum where all the implications of operating jets from carriers could be put on the table. Instead, the USN moved along administratively through a series of negotiations among the organizations concerned. This was not a *failed* process—it produced carrier bombers capable of carrying nuclear weapons. But it was a *flawed* process, in that it needed the RN's innovations to make *Forrestal* and its successors effective strike platforms.

There is another factor to consider, that of creative and perceptive individuals. The RN had the creative engineer Lewis Boddington, the gifted test pilot Eric Brown, and officers like Dennis Cambell and Nick Goodhart. The U.S. Navy

drew on the talents of such aeronautical engineers as Edward Heinemann of Douglas Aircraft; on its own test pilots, like Donald Engen; and on the bureaucratic support provided by such officers as Rear Admiral (later Admiral) Arthur W. Radford, DCNO(Air) from January 1946 through February 1947. There was plenty of talent available to both navies, but having the right individuals in the right place at the right time is often a matter of chance, and chance favored the RN.

Still, making the best use of their talents does not have to depend on chance, which is why integrating organizations and processes are important. Committees are often disparaged as places where officials waste time. But committees and meetings of the right sort are often essential if innovation is to take place. It was from one such committee that the angled-deck concept came, and it was through meetings between U.S. and Royal Navy officers that the concept made its way from Britain to the United States.

Finally, why did the RN's innovations "jump the gap" so quickly between navies? The answer is clear from the available evidence. The close contact between U.S. Navy and RN officers and civilians that had developed during World War II continued afterward. There were exchange programs for test pilots; information was passed from American naval and aeronautical engineers to their British counterparts, and vice versa; and contacts made between senior uniformed officers facilitated communications. For example, Rear Admiral James Russell, BuAer chief in 1955, was a good friend of the RN's Dennis Cambell.

Perhaps the most important "lesson learned" is that uncertainty must be recognized and then dealt with openly and systematically in order for innovation to take place. The RN's officers saw right away that operating jets from aircraft carriers was a challenge and that overcoming that challenge would require innovative thinking. Civilians like Lewis Boddington accepted the challenge and innovated accordingly. When the flexdeck seemed to be not the right answer, Boddington jumped quickly to the angled deck. He and his colleagues dropped the flexdeck without asking for a chance to modify it. Their aggressive pursuit of *something that would work* marked the team of developers at Farnborough, and it seems always to be the mark of real innovators.

NOTES

The authors have developed the article's argument, background, and evidence in greater detail in *Innovation in Carrier Aviation*, forthcoming in 2011 from the Naval War College Press as the thirty-seventh in its Newport

Papers monograph series. Newport Paper 37 will be available for sale online by the U.S. Government Printing Office and in PDF format on the Naval War College Press website.

1. Norman Friedman, *U.S. Aircraft Carriers: An Illustrated Design History* (Annapolis, Md.: Naval Institute Press, 1983), p. 263.
2. Forthcoming from the Naval War College Press as number 37 in its Newport Papers monograph series.
3. Norman Friedman, *British Carrier Aviation: The Evolution of the Ships and Their Aircraft* (London: Conway Maritime, 1988), chap. 13.
4. Geoffrey Cooper, *Farnborough and the Fleet Air Arm* (Hersham, Surrey, U.K.: Midland, 2008). See also "Undercarriage-less Aircraft, Operation from Aircraft Carriers: Development," minutes of a meeting held at the Ministry of Aircraft Production (MAP) on 18 April 1945 (SB61567), folder AIR 2/5785, Public Record Office, Kew, Richmond, Surrey, U.K. [hereafter PRO].
5. "Operation of Undercarriage-less Aircraft: Proposed Programme of Experimental Work," 7 June 1945 (Naval/2001-4/LB/43), folder Avia 13/654, PRO, p. 3.
6. L. Boddington, "Assisted Take-off for Future Naval Aircraft (A paper for discussion at the Naval Aircraft Research Sub-committee on 17th July)," folder Avia 13/654, PRO, p. 1.
7. Friedman, *U.S. Aircraft Carriers*, pp. 227, 230.
8. *Ibid.*, p. 228. Captain Rassieur was a member of the informal advisory board that Vice Admiral Mitscher had wanted DCNO(Air) to create. See Chief of Naval Operations [hereafter CNO], memorandum to the twenty-six members of the board, "Advisory Board to assist CNO (DCNO[Air]) in formulating Recommendations as to the Characteristics of Naval vessels whose primary function is carrying and tending aircraft," 27 April 1945, Op 31-F-HBT:mlu, SC S1-1/CVB, ser. 099131. This memo was in the CominCh/CNO 1945-46 files at the Naval Historical Center (now Naval History and Heritage Command, hereafter NHHHC), in the Washington Navy Yard, Washington, D.C., when Dr. Friedman conducted the research that resulted in his *U.S. Aircraft Carriers*.
9. Friedman, *U.S. Aircraft Carriers*, p. 229.
10. *Ibid.*, pp. 231-32, 241. Rear Admiral Sallada described the results of studies of large, long-range turboprop carrier aircraft in a memo to CNO on 11 December 1945; see Chief, BuAer, memorandum, "Development of Large Bombers for Carrier-Based Operations; Discussion of," ser. C30035. CNO approved Sallada's recommendation that the Navy pursue the development of long-range carrier bombers and their escorts in a memorandum to BuAer, "Development of Large Bombers for Carrier-based Operations; program for," 28 December 1945, ser. 042P517, doc. 193018. Copies of these memos are in the SCB-6 file (on the canceled carrier *United States*) held by the Naval Aviation History office of NHHHC.
11. Friedman, *U.S. Aircraft Carriers*, p. 241. Admiral Ramsey's directive to DCNO(Air) "to proceed with a detailed design study of the large bomber" is discussed briefly in CNO, memorandum to Op-04 and Op-05, "Development of Large Bombers and a New Class Aircraft Carrier for Long Range Operations," 7 February 1946, Op-09/EAH/ky, SC F1-5, ser. 09P09, CominCh/CNO 1945-46 files.
12. Friedman, *U.S. Aircraft Carriers*. A discussion of the two designs is in Chief, BuAer, memorandum to CNO, "Future Aircraft Carrier Design," 28 December 1945, Aer-E-34-GBC, CV/S1-1. This memo and those of 11 and 28 December referred to in note 10 above were in the CominCh/CNO 1945-46 files consulted by Dr. Friedman in his research for *U.S. Aircraft Carriers*.
13. "Outline Specification for Class VB Airplane" (OS-106), 14 January 1946, VB BuAer Correspondence Files, 1946, vol. 2 ("from Jan. 1st"), Record Group [hereafter RG] 72, National Archives and Records Administration [hereafter NARA].
14. Head, Aviation Design Research Branch (BuAer) to Director, Research & Development (BuAer), "Conference on Long Range Carrier Based Bomber: Results of," 15 March 1946, VB BuAer Correspondence Files, 1946, vol. 2, RG 72, NARA.
15. BuAer General Representative, Wright Field, Dayton, Ohio, to BuAer AC-5, "Air Materiel Center Design Proposals for Medium and Heavy Bombers: Forwarding of Information on," 7 June 1946, VB BuAer Correspondence Files, 1946, vol. 2, RG 72, NARA.
16. Jerry Miller, U.S. Navy [hereafter USN] (Ret.), *Nuclear Weapons and Aircraft Carriers: How the Bomb Saved Naval Aviation* (Washington, D.C.: Smithsonian Institution Press, 2001), p. 32.

17. John L. Sullivan to "The President," 24 July 1946, Op-602/cmf, SC A-23, ser. 0014P602, CominCh/CNO 1945–46 files.
18. Miller, *Nuclear Weapons and Aircraft Carriers*, p. 94.
19. Capt. George B. Chafee, "Carrier Requirements for Future Aircraft," *Naval Aviation Confidential Bulletin*, July 1947, p. 19. Chafee describes the process of loading an AJ Savage with a nuclear weapon on the flight deck of a *Midway*-class carrier.
20. "Undercarriage-less Aircraft, Operation from Aircraft Carriers: Development."
21. Cooper, *Farnborough and the Fleet Air Arm*, p. 274.
22. *Ibid.*, pp. 274–75.
23. Eric Brown, *Wings on My Sleeve* (London: Orion Books–Phoenix, 2007), pp. 177–78.
24. *Ibid.*, p. 179.
25. *Ibid.*, p. 190.
26. Chafee, "Carrier Requirements for Future Aircraft," pp. 16–17.
27. Vice Adm. Alfred M. Pride, "Oral History," no. 84, vol. 4, Naval Historical Collection, Naval War College, Newport, R.I.
28. Asst. Sec. of the Navy for Air John E. Floberg, "Trends in Naval Aviation," *Naval Aviation Confidential Bulletin*, February 1953, pp. 2–6.
29. Jan Jacobs, "Follow the Bouncing Cougar: The Flexdeck Program," *Hook* 12, no. 1 (Spring 1984), pp. 11–19. An article in the *Naval Aviation Confidential Bulletin* ("New Concepts in Carrier Deck Design," May 1953), pp. 2–8, noted, "It is recognized that the handling-equipment problem is one of the most serious that must be overcome in order to make the flexdeck concept work under all operational conditions" (p. 6). This was the same point made by Captain Cambell of the Royal Navy [hereafter RN] in 1951. See note 34 below.
30. The aircraft were the Convair XFY-1 Pogo, with contra-rotating propellers and a turbo-prop engine, and the Lockheed XFV-1 Salmon, a similar tail-sitting design.
31. The quotation is from a November 1947 BuAer letter cited by Friedman in his *U.S. Aircraft Carriers*, p. 244.
32. Data on both aircraft are in Gordon Swanborough and Peter M. Bowers, *United States Navy Aircraft since 1911*, 2nd ed. (Annapolis, Md.: Naval Institute Press, 1976), pp. 457–58.
33. Friedman, *U.S. Aircraft Carriers*, p. 244.
34. One notorious incident is recounted in John T. Hayward and C. W. Borklund, *Bluejacket Admiral: The Navy Career of Chick Hayward* (Annapolis, Md., and Newport, R.I.: Naval Institute Press and Naval War College Foundation, 2000), pp. 191–92.
35. Rear Adm. Dennis R. F. Cambell, RN, "The Angled Deck Story," no. 89-4-1, Dennis R. F. Cambell Collection (Coll. 337), Operational Archives, NHHC, p. 2. The notes of the meeting (no. 89-4-8), "Notes of D.N.D.P./D.C.N.R. (A)'s Meeting on 7.8.51 to discuss the Formulation of a Staff Requirement for the operational Version of the Flexible Deck," are in the same folder.
36. Boddington's note to the RN's Deputy Director of Naval Construction (also sent as a copy to Captain Cambell) is dated 28 August 1951. It is also in the Cambell Collection in the Operational Archives, NHHC.
37. Cdr. Harold L. Buell, USN (Ret.), "The Angled Deck Concept: Savior of the Tailhook Navy," *Hook* 15, no. 3 (Fall 1987), p. 14.
38. Pride, "Oral History," p. 197. On the "flight deck cruiser" of the 1930s, see Alan D. Zimm, "The U.S.N.'s Flight Deck Cruiser," *Warship International* 16, no. 3 (1979), pp. 216–45.
39. The close cooperation between the USN and the RN during World War II was no secret. See Owen Rutter, *The British Navy's Air Arm* (New York: His Majesty's Stationery Office and Penguin Books, 1944).
40. "Report of the visit of Mr. J. L. Bartlett & Mr. D. W. Smithers to the USA, November 1948," Naval Construction Department, folder ADM 281/109, PRO, p. 4. RN liaison officers are listed in BuAer phone books from this period; "BuAer, Directories & Correspondence Designations, 1 February 1946, 1 July 1946, 15 January 1947, 15 April 1947, 10 November 1947," box 88, Naval Aviation History Unit, NHHC.
41. Cambell, "Angled Deck Story," p. 3.
42. Brown, *Wings on My Sleeve*, p. 220.

43. Buell, "Angled Deck Concept," p. 14.
44. *Ibid.*, p. 19.
45. Chafee, "Carrier Requirements for Future Aircraft," pp. 17–18.
46. Chief, BuAer, to Naval Air Materiel Center, 14 Jan. 1949, file S83-2(C), 1949, vol. 1, BuAer Confidential Correspondence, RG 72, NARA. See also "Outline of ADM Pride's speech at the Naval Academy, 24 Mar. 1949," folder "BuAer, Naval Aviation programs," box 93, NAVAIR/BuAer, "Naval Aviation Programs, Etc.," Naval Aviation History Unit, NHHC, p. 4.
47. See the letters of 9 June 1949 (ser. 3125853) and 15 June 1949 (ser. 3125989), file S-83-2(C), vol. 2, BuAer Confidential Correspondence, RG 72, NARA.
48. Naval Aircraft Factory to BuAer, 8 October 1951, ser. 0482, file S83-2(C), vol. 3, 1951, BuAer Confidential Correspondence, RG 72, NARA.
49. U.S. Naval Attaché, London, "Trials of prototype steam catapult in HMS *Perseus*," information report, Office of Naval Intelligence, 27 July 1951, Project Records Relating to Catapults, Launchers, Missiles, 1941–1953, box 3, entry 133, RG 72, NARA, p. 5.
50. Capt. Sheldon W. Brown, memorandum to Rear Adm. Lucien M. Grant, "Brief Comparison of British and American Slotted Cylinder Catapults," 8 January 1952 (Aer-SI), *Perseus* file, Project Records Relating to Catapults, Launchers, Missiles, 1941–1953, box 3, entry 133, RG 72, NARA.
51. Daniel K. Weitzenfeld [Rear Adm., USN (Ret.)], "Colin Mitchell's Steam Catapult: The Heart of Modern Aircraft Carriers," *Wings of Gold* 10 (Summer 1985), pp. 41–46.
52. Cooper, *Farnborough and the Fleet Air Arm*, p. 210.
53. Donald D. Engen [Vice Adm., USN (Ret.)], "Roger, Ball: How It Started," *Hook* 15, no. 3 (Fall 1987), p. 24. See also "It's Done with Mirrors," *Naval Aviation News*, November 1955, pp. 20–22.
54. Friedman, *U.S. Aircraft Carriers*, p. 257.
55. Thomas C. Hone, Norman Friedman, and Mark D. Mandeles, *American & British Aircraft Carrier Development, 1919–1941* (Annapolis, Md.: Naval Institute Press, 1999).
56. The "deck park" was a concept developed in the USN in the 1920s. As aircraft returned to a carrier, they were "parked" forward on the flight deck, shielded by wire barriers from planes landing. When all the planes had landed, the barriers were lowered and the planes in the deck park forward were pushed aft, where they were readied for their next flights.
57. Cooper, *Farnborough and the Fleet Air Arm*, pp. 200–205.
58. For details on the debates over roles and missions and the responsibility for the nuclear strike mission, see Jeffrey G. Barlow, *Revolt of the Admirals: The Fight for Naval Aviation, 1945–1950* (Washington, D.C.: Naval Historical Center, 1994). For details on jet engine development, see Mark D. Mandeles, *The Development of the B-52 and Jet Propulsion: A Case Study in Organizational Innovation* (Maxwell Air Force Base, Ala.: Air University Press, 1998), and Tommy H. Thomason, *U.S. Naval Air Superiority: Development of Shipborne Jet Fighters, 1943–1962* (North Branch, Minn.: Specialty, 2007).
59. For an overview of this period, see Jeffrey G. Barlow, *From Hot War to Cold: The U.S. Navy and National Security Affairs, 1945–1955* (Stanford, Calif.: Stanford Univ. Press, 2009).
60. Chafee, "Carrier Requirements for Future Aircraft," p. 17.
61. Friedman, *U.S. Aircraft Carriers*, p. 271.