# R.O. King: The Professional Odyssey of a Practical Canadian Engineer


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*R.O. King était un ingénieur canadien reconnu pour son travail sur les moteurs à combustion interne et les applications marines à base de technologies d'air comprimé. Il a passé beaucoup de sa vie professionnelle aux Etats-Unis et en Grande-Bretagne de 1911 jusqu'à son retour vers le Canada en 1940. Ses études à l'université McGill de Montréal lui ont gagné des contrats de recherche avec la marine de guerre des Etats-Unis et puis avec la royale britannique. A partir de 1917 King a étudié le cognement dans les moteurs d'avions au Ministère de l'air britannique et à l'Université de Cambridge. Il a rejoint le Conseil d'inventions canadian en 1940, puis il a assumé une position de chercheur au Quartier général du service naval en 1942; enfin il a été nommé au nouveau Conseil de recherches de la défense en 1948, où il est resté en tant que conseiller jusqu'à sa retraite, à l'age de 85 ans, en 1959.*


## 1. Introduction

In 1899 American writer James P. Boyd trumpeted that "it may be said that along many of the lines of inventions and progress which has most intimately affected the life and civilization of the world, the nineteenth century has achieved triumphs and accomplished wonders equal, if not superior, to all other centuries combined."[1] Canadian men of science, haughtily dismissed by such figures as literature professor James Cappon as "educated plumbers," were far less optimistic. Thanks to such attitudes and recessions that had retarded Canada's development since 1867, they lacked access to jobs and laboratories at home. The result, James Loudon, the University of Toronto's first Canadian-born president, angrily noted in the late 1890s, was that 80 of his science graduates had left for America, an unsustainable brain drain. Even when Canada had jobs for engineers, as J. Rodney Millard's study of Canadian engineering reveals, Americans

1 Boyd cited in Merritt Roe Smith, "Technological Determinism in American Culture," in Merritt Roe Smith and Leo Marx, ed., *Does Technology Drive History? The Dilemma of Technology Determinism* (Cambridge: The MIT Press, 1998), p. 7.


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held many of the senior positions.[2]

Robert Owen King, an engineer and scientist renowned for pioneering work on hydrogen as a fuel for spark ignition engines, exemplified the brain drain. He had been born in Port Hope, Ontario, on 17 October 1874, to an English immigrant father and a second-generation Canadian-Scottish mother, was educated at Montreal's McGill University. Unable to find professional opportunities in Canada, King undertook a 25 year-long odyssey in America and Britain. Then, at an age when most men retire to gardens or stamp collections, in 1940 King began another research career with Canada's National Research Council (NRC). Later employed by the Royal Canadian Navy (RCN) and the Defence Research Board (DRB), King worked full time until retiring in 1959. An extraordinarily active researcher, King toiled in such diverse fields as the thermal conductivity of metals, ship salvage, anti-torpedo systems, water jet boat propulsion for submarines, engine lubricating oil, carburetors, exhaust silencing mechanisms, "knock" in spark ignition engines and hydrogen combustion. Engaged in basic research for decades, King made his first patent application in 1899, his last in 1957.[3] He received 31 patents, covering inventions from greenhouse trusses to carburetors, ship salvage to chemical reactors, and published 58 papers in technical journals. Looking back on King's fascinating career not only reveals a talented Canadian researcher and scientist, it also illuminates the problems and progress of science and engineering in a still maturing Canada.

## 2. Education and Early Career

King completed two years of secondary school before training as a machinist in Montreal. He decided that he wanted to study at McGill University, and obtained the required secondary school graduation qualifications on his own, including a 97.5 per cent average in four mathematics courses.[4] Initially in the mechanical engineering program, King switched to electrical engineering to compete for the British Association Gold Medal. He graduated in 1895 with the Gold Medal and honours standing as class president (Figure 1). Awarded the Exhibition of 1851 Scholarship for postgraduate physics research, King toiled for a year in Harvard University's Jefferson Laboratory thanks to a Whiting Fellowship before returning to McGill to complete the 1851 award under Professor H.L. Callendar. There was a fruitful partnership of Callendar's

2 Cappon and Loudon cited in Rod Millard, "The Crusade for Science: Science and Technology on the Home Front, 1914-1918," in David Mackenzie, ed., *Canada and the First World War: Essays in Honour of Robert Craig Brown* (Toronto: University of Toronto Press, 2005), p. 313; and J. Rodney Millard, *The Master Spirit of the Age: Canadian Engineers and the Politics of Professionalism 1887-1922* (Toronto: University of Toronto Press, 1988), pp. 54-55.

3 R.O. King and Wheatley, "Recording Passage of Electric Cars," UK patent submission number 4224, 1899, abandoned in February 1925; and R.O. King, "Method and Apparatus for carrying out Thermal Decompositions", US Patent Nº 2,786,877 awarded 26 March 1957.

4 R.O. King, unpublished "Autobiography," 1959, p. 1 (in possession of Professor Michael F. Bardon).

theoretical brilliance with King's practical flair and precision in experimentation. King, while at Harvard, had used principles suggested by Callender for the experimental determination of one of copper's various electrical properties, and the young researcher was able to publish results in 1898.[5] The project required measuring minute values of electrical resistance and painstaking care in eliminating or making allowance for experimental errors. That contribution was King's alone, a meticulous experimental method that became the hallmark of his subsequent studies.

King's knack for solving experimental problems was vividly demonstrated by his work on X-rays. W.C. Roentgen's stunning discovery in Germany in December 1896 that X-rays could photograph bones incited many to duplicate the feat. Professor J. Cox of McGill's Physics Department set up an X-ray apparatus but produced poor quality images. Knowledgeable about practical photography but "not in a position to tell the Head of the Department how the experiments should be carried out," King and fellow student F.H. Pitcher used the X-ray laboratory after hours. Using external wrapping as a filter to control exposure, King made an excellent X-ray of his right hand, a copy of which Cox "demanded" for inclusion in a paper published in *The Montreal Medical Journal* (Figure 2). King and Pitcher received only brief mention.[6] Cox exploited this improvement for medical diagnoses, and the technique soon allowed Montreal doctors to use X-rays to locate a bullet imbedded in a man's leg. That acclaimed triumph, long thought to be the first published medical diagnostic case study using X-rays, was in fact preceded slightly by a British case.[7]

Awarded an MSc in physics in 1897, King remained at McGill as a poorly paid senior demonstrator in physics and a lecturer in mechanics. Initially taking consulting and tutoring work to make ends meet, in 1901 King became a production engineer in a Montreal factory that produced typesetting machinery. His salary was twice what he had earned at McGill. Within a year, he led the manufacturing operations. Claiming the firm was set to be "absorbed by the Linotype Company," King resigned in 1902 to design and manufacture greenhouses with his father. While R.W. King operated the business in Georgetown, Robert established a branch at Buffalo, New York. The company's specialties included commercial greenhouses, conservatories for private estates and public gardens, and light commercial buildings for clients as far afield as Britain, France, and Germany. King devised numerous construction innovations during this period,

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5 R.O. King, "An Absolute Measurement of the Thomson Effect in Copper," *Proceedings American Academy of Arts & Sciences* (1898), pp. 353-379.

6 King "Autobiography," p.1; and J. Cox and Robt. C. Kirkpatrick, "The new photography with report of a case in which as bullet was photographed in the leg," *The Montreal Medical Journal* vol. 24, (March 1896), pp. 661-665. The 1898 edition of the *Old McGill* states that Pitcher and Barnes took the initial x-ray. The copy is corrected in the margin, with Barnes crossed out and R.O. King pencilled in: "X Rays at McGill," *Old McGill 1898*, McGill University Archives.

7 King, "Autobiography," p. 1; and Charles G. Roland, "Priority of Clinical X-Ray Reports: A Classic Dethroned," *Can Journal of Surgery* vol. 5, (July 1962), pp. 247-252.

*Illustration 1: R.O. King 1908 at the Time of his Ship Salvage Work. Source:* Technical World Magazine*, (October 1908), pp.136-143.*

receiving eight American and two Canadian patents.[8] Yet it was in compressed air technologies that King would make his first major engineering innovation.

## 3. Greenhouses and Ship Salvage

Ship salvagers abandoned the use of compressed air to expel water from a sunken vessel and refloat it after a German group employing this method blew the hull of *Mount Olivet* to pieces in January 1903.[9] In 1905 other techniques tried at great expense to salve the Canadian Allan Line steamship RMS *Bavarian* after she ran aground near Quebec City failed. King, believing the vessel could be recovered, partnered with W.W. Wotherspoon and an American group that was using compressed air to build a tunnel in New York City. After measuring the ship's holds and local tides, King convinced his new partners (who included Diamond Jim Brady[10]) that compressed air would be practicable. Combining with Canadian Salvage Company, Wotherspoon and King refloated the ship in November 1906. King bought the boat, only to lose it when a storm and a collision with another vessel broke its back. Canadian Salvage went bankrupt, leaving King with "a loss of money and a pair of very fine candlesticks


*Illustration 2: King's Successful X-ray Photograph of his Hand. Courtesy: Mrs F.R.B. King.*

8 King, "Autobiography," p. 2; R.O. King, "Sash-Bar or Rafter," US Patent N° 1,008,343, awarded 14 November 1911; King, "Rafter-Bracket," US Patent N° 1,010,771, awarded 5 December 1911; King, "Clip for Connecting Rafters, Purlins, and Sash-Bars of Greenhouses," US Patent N° 1,048,704, awarded 31 December 1912; King, "Building," US Patent N° 1,056,103, awarded 18 March, 1913; King, "Building," US Patent N° 1,076,290, awarded 21 October 1913; King, "Composite Rafter," US Patent N° 1,094,074, awarded 21 April 1914; King, "Truss-Coupling," US Patent N° 1,165,419, awarded 28 December 1915; King, "Construction of Horticultural Buildings," US Patent N° 1,170,911, awarded 8 February 1916; King, "Green Houses," Canadian Patent N° 131798, issued 13 March 1911; and King, "Green Houses," Canadian Patent N° 154688, issued 14 March 1914.

9 C.F. Carter, "Compressed Air Saves Wrecks," *Technical World Magazine* (October 1908), pp. 136-143.

10 James Buchanan Brady, 1856-1917, made a fortune in the railway business and stock trading. Renowned for his fondness for New York's night life, a penchant for jewelry and gold, and an enormous appetite for food and drink, Diamond Jim Brady was the first person in New York City to own a car (1895). He left his fortune to various public institutions; see H. Paul Jeffers, *Diamond Jim Brady: Prince of the Gilded Age*, E-Book, 2001.

from the Captain's cabin." Wotherspoon, facing the seizure of the salvage equipment by the local sheriff, bribed a ferry captain to delay buyers interested in the gear, allowing Wotherspoon to buy back the gear "at scrap prices."[11]

King obtained four US and two Canadian patents for his compressed air systems from 1906 to 1910,[12] patents put to good use in April 1908 when he and Wotherspoon salvaged the Canadian Pacific Railway steamship *Mount Temple* near Halifax. *Technical World Magazine* proclaimed that King and Wotherspoon, "two young American engineers," had restored "to American wreckers the world leadership they held up to 1840."[13] This article, King remarked, "obtained wide publicity." In September 1908 a United States Navy (USN) auxiliary cruiser, USS *Yankee*, had run aground. Landing an $85,000 contract to refloat the vessel, Wotherspoon and King used compressed air to lift the ship on 4 December, but weakened by pounding seas, it foundered. A similar operation with the USS *Nero*, however, succeeded.[14] This work soon took King in another direction.

## 4. World War I: Torpedo Protection and Submarine Technology

Self-propelled torpedoes, greatly improved in range, speed and stability by the beginning of the twentieth century, seriously menaced the battleship's maritime supremacy. Safeguarding ships from a torpedo attack, British Admiral R.H.S. Hughes commented in 1910, "has hitherto baffled all solution." As naval historian Norman Friedman explains, "there could never be any hope that any reasonable weight of armor outside the ship could resist the explosion of several pounds of TNT *in contact* with it, an explosion amplified by the water around it." The trick was take advantage of the fact that the explosive effect dissipated rapidly over distance by finding methods to absorb the

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11 Wotherspoon's uncle, an admiral in the US Navy, supervised six tugs towing the *Bavarian*. The admiral spoke only English, the tug captains only French, leading to a "confusion of orders" that brought on the collision; King, "Autobiography," pp. 5-6. King's process for raising the *Bavarian* is described in "Remarkable Rescues of Ships Wrecked at Sea," *The Washington Post* (14 April, 1907), p. A4; and "Compressed Air and Its Uses," *The Washington Post* (23 November 1906), p. 6. Some of the medical problems encountered during the building of the New York City tunnel are explored in John L. Phillips, *The Bends: Compressed Air in the History of Science, Diving, and Engineering* (New Haven: Yale University Press, 1998).

12 W.W. Wotherspoon and R,O. King, "Vessel Construction," US Patent N° 851,269, awarded 23 April 1907; Wotherspoon and King, "Method of Floating Sunken or Stranded Vessels," US Patent N° 851,270, awarded 23 April 1907; King, "Method and Apparatus for Wrecking Bodies Sunk in Water", US Patent N° 975,534, awarded 15 November 1910; King, "Vessel Construction," US Patent N° 988,354, awarded 4 April 1911; Wotherspoon and King, "Vessel Construction," Canadian Patent N° 108203, filed 1 December 1906; Wotherspoon and King, "Method of Floating Sunken or Stranded Vessels," Canadian Patent N° 108204, filed 9 January 1907.

13 Carter, "Compressed Air Saves Wrecks," pp. 137-138.

14 King, "Autobiography," pp. 5-6; and Homepage of the Massachusetts Office of Coastal Zone Management, downloaded on 1 January 2006.

blast. Navies toyed with many ideas, including employing cellulose matting built into the hull to float a damaged ship, surrounding a ship with mesh protective screening, constructing watertight internal compartments, adding belted armour, and placing coal bunkers to cushion torpedo blasts. All had problems; they reduced mobility, cost too much, added weight, or were ineffective.[15]

The USN was consumed by a bitter debate between old line officers like Admiral A.T. Mahan who disdained technological solutions in favour of tactics and strategy distilled from study of the art of war, and "Young Turks" who championed new weapons and propulsion systems.[16] In 1895 Lt. F.F. Fletcher told the USN's Torpedo Board that even "under the most favorable conditions the actual value of the torpedo in battle between ships will be far less than what has generally been assigned to it." Its value lay "more in the direction of a moral influence as a deterrent to hamper their manoeuvres of the enemy." Six years later, citing Mahan's dictum that "effective defense does not consist primarily in the power to protect but the power to injure," Commander W.W.

15 Rear Admiral R.H.S. Hughes, "The Battleship of the Future," in R.W. Dana, ed., *Transactions of the Institution of Naval Architects* vol. 52 (1910), p. 2; and Norman Friedman, *Battleship Design and Development 1905-1945* (New York: Mayflower Books, 1978), p. 77; Lt. Albert Gleaves, USN, (translator), "A Proposed Non-Sinkable Battle-Ship with a Constant Water-Line,"*Proceedings of the United States Naval Institute* vol. 14 (No. 3, 1888), pp. 600-603; Commander Murray F. Sueter, RN, *The Evolution of the Submarine Boats Mine and Torpedo from the Sixteenth Century to the Present Time* (Portsmouth: J. Griffin and Co., 1907), pp. 334-336; and William Hovgaard, *Modern History of Warships* (London: E. & F.N. Spon Ltd., 1920), pp. 472-473. The RN had experimented with double hulls in the 1870s and 1880s, using a thin outer hull to absorb a torpedo strike's explosive power. This testing was abandoned due to cost and technical problems; Alan Cowpe, "The Royal Navy and the Whitehead Torpedo," in Bryan Ranft, ed., *Technical Change and British Naval Policy 1860-1939* (London: Hodder & Stoughton, 1977), p. 26 With the arrival of the *Dreadnought* class, the RN opted for problematic interior bulkheads; Friedman, *Battleship Design and Development*, p. 79.

16 For example, the Civil War ironclad frigate *New Ironsides* had but one machine, its two engines, while the battleship *Iowa*, commissioned in 1896, employed 71 different mechanisms; Ronald Spector, *Professors of War: The Naval War College and the Development of the Naval Profession* (Washington DC: Government Printing Office, 1977), p. 5. For a description of this battle, see Spector, *Professors of War*; Lt. John B. Hattendorf, USN, "Technology and Strategy: A Study in the Professional Thought of the U.S. Navy, 1900-1916," *Naval War College Review*, vol. 24 (November 1971), pp. 25-48; John C. O'Reilly, "U.S. Naval Intelligence and the Ordnance Revolution, 1900-1930," in Robert William Love, Jr., ed., *Changing Interpretations and New Sources in Naval History* (New York: Garland Publishing, 1980), pp. 325-339; and William McBride, *Technological Change and the United States Navy, 1865-1945* (Baltimore: The Johns Hopkins University Press, 2000), Chapters 2 and 3. The battle between the pro- and anti-technology factions grew so bitter that in 1882, the old line officers eliminated the Naval Academy's engineering curriculum for almost a decade; William H. MacBride, "From Measuring Progress to Technological Innovation: The Prewar Annapolis Engineering Experiment," in Steven A. Walton, ed., *Instrumental in War: Science, Research, and Instruments Between Knowledge and the World* (Leiden: Brill, 2005), pp. 228-229.

Kimball asserted the submarine with "its invulnerable defense of water cover and strong offensive power of her torpedoes" could circumscribe battleship operational capabilities.[17] One solution, proposed in 1904 by Commander Bradley Fiske, was to build heavily armoured and torpedo-equipped battleships able to keep an enemy at least 4,000 yards away, well beyond torpedo range. In April 1909, the USN's General Board opted for interior protective armour in new battleships, an idea France rejected in 1907. The conclusion of the USN's Bureau of Ordnance in 1912 that battleships could be protected only by "entirely removing them the line of battle or from the proximity of the enemy" seemed unfitting for warships that were "the core of naval existence, a weapon that symbolized practically everything that line officers held to be true about life and war."[18]

Could the USN do the job itself? While the navy's Engineering Experiment Station, set up in 1908, undertook "scientific" research, historian William MacBride states the facility focused on mundane instrumentation and measuring tasks. The USN, as Lt. Commander H.C. Dinger admitted in 1915, "relies on the commercial engineering field for the excellence of the products from which the material matters of our naval forces are constructed." King contended that it was his salvage of the *Bavarian* and the *Mount Temple* that led the USN in 1911 to invite him to Washington DC to work on battleship defence. That recollection may have been self-serving for the USN's archives show that King and Wotherspoon approached the navy to demonstrate how compressed air technology "could prevent loss of buoyancy."[19] Compressed air technology was not new to the USN. In 1872, the *Intelligent Whale* submarine had used compressed air to expel water to resurface, while compressed air had operated the USS *Terror's* engines and gun turrets in the 1890s. Nor was the employment of compressed air to keep a damaged warship afloat a novel notion. In 1907, RN Commander Murray Sueter had suggested that cushions of compressed air built into a ship's hull could dissipate a torpedo's

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17 Lt. F.F. Fletcher to President of the Torpedo Board, September 1895, Washington Chambers Papers, box 33, file Ordnance – Torpedoes General Info, Library of Congress [LC]; and Commander W.W. Kimball, USN, "Submarine Boats: Tactical Value and Strategical Considerations," *Proceedings of the United States Naval Institute* vol. 27 (December 1901), pp. 739-746.

18 Commander Bradley A. Fiske, "Compromiseless Ships," *Proceedings of the United States Naval Institute* vol. 31 (1905), p. 550; minutes of the General Board, 8 April 1909, Proceedings and Hearings of the General Board of the United States Navy 1900-1950, RG80, M1421, reel 2, National Archives and Records Administration, [NARA]; and report of the First Committee of the General Board, attached to General Board Minutes of 19 December 1907, ibid; memorandum for Chief of the Bureau of Ordnance, "Subject – Torpedo Nets," 29 November 1912, Records of the Bureau of Ordnance, Entry 1001, General Correspondence 1907-1949, Entry 1001, RG74, box 1, file 1912, NARA; and Robert L. O'Connell, *Sacred Vessels: The Cult of the Battleship and the Rise of the U.S. Navy* (Boulder: Westview Press, 1991), p. 80.

19 King, *Autobiography*, p. 7; and Navy Department memorandum, 21 July 1910, General Records of the Navy Department, General Correspondence 1897-1915, RG80, box 1326, file 26813-1230, NARA.

explosive effect.[20] King and Wotherspoon were contracted to experiment on the armoured cruiser USS *North Carolina* as well as the battleships *Utah* and *Florida* to see if permanently installed fittings, piping and compressors would keep damaged vessels afloat by pumping compressed air into damaged compartments and forcing out water. As Fiske commented, if King's design worked "the beneficial results will be too obvious to need detailing" as it would minimize "the destructive effect of the torpedo."[21]

Captain C.C. Marsh reported that tests carried out on part of the *North Carolina* on 1 November 1911 had demonstrated "how well the present equipments of the ship lend themselves to the plan of applying compressed air." The system had not leaked, it had not damaged the vessel, and the tests had revealed "small leaks in the water tight hull." Marsh initially wanted to test the entire ship, yet as often happens in defence contracts, other factors came into play. First, Marsh feared King and Wotherspoon might demand royalties for additional work. Second, testing on the *Utah* indicated that existing bulkheads might not withstand a constant uniform air pressure, meaning the structure would have to be strengthened at considerable expense. Uncertain about patent rights that King and Wotherspoon might claim, a cost-conscious Navy Department opted on 8 November to end the *North Carolina* tests.[22] On 28 December Wotherspoon asked permission to install compressed air machinery on the *Iowa*, the *New York*, and the *Texas*. A.S. Watt, head of the Navy Department's Bureau of Construction and Repairs (BCR), approved the *Iowa* request as long as Wotherspoon provided a detailed cost estimate but rejected the other offers on the grounds of "insufficient funds."[23] Wotherspoon's estimate for the *Iowa* test was $6,400., and, never reticent, he also asked to examine the *Idaho* and the *Missouri* at a price of $1,300.00. Watt, calling King's system "experimental," considered "it inadvisable to authorize additional installations at this time."[24] Indignant their technology had been called "experimental," Wotherspoon protested that he and King

20 MacBride, "From Measuring Progress to Technological Innovation," pp. 218 and 234; "*Intelligent Whale*," in *Dictionary of American Naval Fighting Ships*, downloaded from the Naval Historical Center homepage, www.history.navy.mil/danfs/i2/intelligent_whale.htm on 2 February 2006; "Compressed Air System on the U.S. Monitor Terror," *Proceedings of the United States Naval Institute*, vol. 23 (No. 1, 1897), pp. 165-167; and Sueter, *The Evolution of the Submarine Boat*, pp. 336-337.

21 King, "Autobiography," p. 7; Commanding Officer, *USS North Carolina*, to Commander in Chief USN, no. 309, 31 October 1911, Bureau of Ships – Bureau of Construction and Repair, Correspondence re Ships, "E Documents 1896-1912," RG19, Entry 92, box 1247, file 17753, NARA; Construction Officer to Commandant New York Navy Yard, "Subject – *Utah* – Compressed air water expelling system," 24 October 1911, ibid., box 1696, file 23401; and Fiske to the Secretary of the Navy, 3 November 1911, ibid.

22 Captain C.C. Marsh to the Secretary of the Navy, 3 and 4 November 1911, RG19, Entry 92, box 1247, file 17753, NARA; and R.M. Watt, Chief of the Bureau of Construction and Repairs, to the Secretary of the Navy, "Subject – *North Carolina* – Testing forward compartments below berth deck with air pressure," 8 November 1911, ibid.

23 Wotherspoon to Watt, 28 and 28 December 1911, ibid; and Watt to King and Wotherspoon, 9 January 1912, ibid; and Wotherspoon to Watt, 27 January 1912, ibid.

24 Wotherspoon to Watt, 13 February 1912, ibid; Watt to King and Wotherspoon, 21 February 1912, ibid.

"think a considerable advance was made in our practice"thanks to ongoing salvage work. On 23 February 1912 Wotherspoon asked again to work on the *Iowa* and to consult with Bureau officers. Emphasizing he and King had "in the past been moderate in our demands of compensation," Wotherspoon maintained that while it appeared "that the advantages are all on our side," the USN too "will be benefitted [sic] by these experiments." Watt tersely responded that the Bureau would not install any additional compressed air systems "until further reports of those now in service shall have been received."[25]

Why did the USN not pursue compressed aid technology? In December 1914 Rear Admiral Frank F. Fletcher, commander-in-chief of the Atlantic Fleet, told Congress that while torpedoes could temporarily obstruct battleship movement, they would "not win battles"; only massed battleships could do that. Rear Admiral Charles Badger of the USN's General Board added that "nothing has occurred to supplant the battleship with any other ship of war or impair the usefulness of the battleship." Fletcher believed improved battleship design was the key, and the USN ordered torpedo nets for the *Oklahoma* and *Nevada* even though the Bureau of Ordnance ruled "that all around torpedo net defense is impracticable."[26] The RN found a better solution in "blister" technology – small compartments attached to a ship's hull to provide protective layers against torpedoes – after a battleship fitted with blisters survived hits by three torpedoes at the Battle of Jutland in 1916. The BCR promptly followed the British example with a four-layer anti-torpedo system using liquid-filled "bulges" and steel interior bulkheads built into the hull. When Wotherspoon appealed to the Chief of Naval Operations on 2 April 1917 to allow him to work "gratis" to prove King's equipment could do the job, the BCR responded that the use of compressed air to eject water from a ship "can not be considered practicable." Wotherspoon's subsequent attempt to circumvent the admirals also failed. On 30 July 1917, Franklin Roosevelt, the Navy's avuncular assistant secretary, agreed to meet with Wotherspoon, but said "it is believed that further discussion of the subject would not modify the Department's decision."[27]

25 Wotherspoon to Watt, 23 and 24 February 1912; and Watt to King and Wotherspoon, 26 February 1912, ibid.

26 McBride, *Technological Change and the United States Navy*, pp. 119-121; J. Strauss, Bureau of Ordnance, to the Navy Department, "Subject: Torpedo Nets," 30 July 1914, RG74, Entry 1001, box 1, file 1914; and "Protection Against Torpedoes," *Proceedings of the United States Naval Institute*, vol. 40 (November-December 1914), p. 1821. The General Board decided in 1910 that new battleships should carry torpedo nets; minutes of the General Board, 18 May 1910, RG80 , M1421, reel 2, NARA.

27 King, *Autobiography*, p. 8; McBride, *Technological Change and the United States Navy*, p. 124; Wotherspoon to Captain J.S. McKean, Assistant for Material, Office of the Chief of Naval Operations [CNO], 2 April 1917, Bureau of Construction and Repair Records, General Correspondence 1912-1925, RG19, box 839, file 15010-A13; Bureau of Construction and Repair to CNO, 25 April 1917, ibid; and Franklin Roosevelt to Wotherspoon, 30 July 1917, ibid., box 839, file 15010-A15. The inner two compartments would contain water or fuel, leaving the innermost and outermost compartments void. A torpedo explosion would expend its energy within the first three layers, leaving the fourth layer to act as a flooding barrier in a

The lingering royalty problem also caused difficulties. In 1913 Wotherspoon and King offered to sell the rights to their compressed air technology to the USN. While the navy could install compressed air systems to test watertight bulkheads and decks without infringing their patents, King and Wotherspoon maintained that the use of the equipment to expel water from damaged compartments without their permission would violate their patents. The Department of Justice concluded tentatively in July 1914 that the patents were "not valid." As late as July 1918 Wotherspoon offered to make transport ships less vulnerable to torpedo attack. The managers of New York's Navy Yard, after meeting with Danish naval construction expert Captain William Hogvaard and a telephone conversation with John Reiss, President of King & Wotherspoon Inc., concluded the company was not "in a position to handle the design or construction" that Wotherspoon had suggested.[28]

King's career had long since taken on a new trajectory following a meeting with the British naval attaché in Washington DC in 1915. After the modern battleship HMS *Audacious* suffered underwater damage from a German mine and sank despite prolonged efforts to save her Admiral Sir John Jellicoe, commander-in-chief of the Grand Fleet ordered experiments to see if compressed air could keep damaged ships afloat. As King learned, the Admiralty had quickly ended the tests after a ship's bulkhead ruptured. When the attaché asked King if he would travel to Britain to discuss his concepts, King sold his interest in the greenhouse business and moved his large family to Britain, his father's homeland.[29]

King's arrival in Britain was opportune. Interaction between British scientists and policy-makers had been ineffective prior to 1914, but as the Great War intensified government intruded upon the jurisdictions of hitherto private industrial and scientific enterprise in the desperate search for potentially war-winning weapons.[30] Britain established a Munitions Inventions Department (MID) in August 1915 and an Air Inventions Committee in 1917, while the Board of Invention and Research (BIR) emerged in July 1915 to serve the Admiralty. As David Lloyd George, minister of munitions and later prime minister, commented, "modern warfare, we discovered, was to a far greater extent than ever before a conflict of chemists and manufacturers." The MID

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worst case scenario to protect machinery spaces; David C. Fuquea, "Task Force One: The Wasted Assets of the United States Battleship Fleet, 1942," *The Journal of Military History* vol. 61 (October 1997), p. 711; and Friedman, *Battleship Design and Development*, p. 81.

28 MacBride, "From Measuring Progress to Technological Progress," p. 219; Roosevelt to the Attorney General of the United States, 21 January 1914, RG80, General Correspondence 1897-1915, box 318, file 8247-193; Watt to the Solicitor of the Navy Department, "Subject: Compressed-Air Water Ejection System," 8 July 1914, ibid; John Reiss to G.E. Burd, Industrial Manager New York Navy Yard, 6 July 1918, RG19, Bureau of Construction and Repairs, box 839, file 15010-A21, NARA; and Burd to Reiss, "Subject: King & Wotherspoon, Inc. – Interior Protection of Vessels," 14 August 1918, ibid.

29 King, *Autobiography*, p. 7.

30 Frank M. Turner, "Public Science in Britain, 188-1919," *Isis* vol. 71 (December 1980), pp. 589-608.

received almost 48,000 suggestions before its activities ended in March 1919.[31] Michael Pattison contends the MID lacked significant achievements until late in the war because it could not establish firm priorities, unlike the BIR with its one whole-heartedly supported objective; "how to catch, render ineffective, or destroy submarines."[32] Inundated by amateur and professional inventors, until the BIR's creation, the Admiralty had six departments winnowing the inventive wheat from the wrong-headed chaff. At the insistence of A.J. Balfour, who succeeded Winston Churchill as First Sea Lord in May 1915, the BIR was a civilian board independent of RN control. Further, Balfour asked Admiral Fisher, who left the RN in 1915 after quarreling with Churchill over the ill-fated Dardanelles campaign, to head the BIR. This controversial choice endowed the BIR "with a certain notoriety and distinction" as Fisher's temperamental personality infused the board's operations until the war's end.[33]

King was "kept waiting for six months" while the BIR debated his compressed air proposal. The delay did not represent a lack of interest in battleship defence as the RN had been experimenting with transverse and continuous bulkheads to counter torpedoes since 1904. However, while Germany had built all of its capital ships to withstand underwater damage, by 1914 just seven of the RN's vessels had complete, but still inadequate, bulkheads, while another 22 had extra protection only for their magazines.[34] Concerned that improved bulkheads alone could not give sufficient protection, on 3 September 1915 the BIR selected Fisher personally to direct a "special investigation" into the problem. Six days later, the BIR's central committee asked Sir Charles Parsons, the turbine's inventor, to judge King's design.[35] King had fallen victim to bad timing. First, on 23 September Parsons said that King's system resembled a design already submitted to the BIR by an RN officer. Second, the BIR was attracted by the promise of "blister" technology. That idea was suggested in October 1914 by the RN's Director of Naval Construction, Tennyson d'Eyncourt, who, with Churchill's support, arranged for some ships to get roughly designed blisters in 1915. Vickers Limited, moreover, wanted to construct an "unsinkable battleship," a vessel with blister technology built into it. As King ruefully noted, the RN opted for blisters rather than compressed air when the battleship HMS *Marlborough*, equipped with blisters, survived three torpedoes at the

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31 David Lloyd George, *War Memoirs. Volume 2* (London: Oldhams Press, 1933), p. 617; and Michael Pattison, "Scientists, Inventors and the Military in Britain, 1915-19: The Munitions Invention Department," *Social Studies of Science* vol. 13 (November 1983), p. 538.

32 Pattison, "Scientists, Inventors, and the Military in Britain," p. 535.

33 Roy M. MacLeod and E. Kay Andrews, "Scientific Advice in the War at Sea, 1915-1917: the Board of Invention and Research," *Journal of Contemporary History* vol. 6 (No. 2, 1971), pp. 3-40.

34 King, "Autobiography," p. 8; and Charles H. Fairbanks Jr., "Choosing among Technologies in the Anglo-German Naval Arms Competition, 1898-1915," in William B. Cogar, ed., *Naval History: The Seventh Symposium of the U.S. Naval Academy* (Wilmington: Scholarly Resources Inc., 1988), p. 130.

35 Minutes of the Central Committee of the Board of Inventions and Research, 3 and 9 September 1915, Admiralty Records, ADM293/7, The National Archives of the United Kingdom [TNA].

Battle of Jutland in 1916.[36]

Characteristically, King was not idle while the BIR debated his compressed air plan. He became interested in using axial flow water jets to control a submarine's attitude and depth control rather than traditional hydrodynamic surfaces such as diving planes. While such planes worked, they dramatically increased drag even at low speeds and thus reduced the submarine's performance. (Figures 3 & 4) King submitted his idea to the BIR in the hope its adoption would allow British submarines to slip through German minefields. The BIR was not enthusiastic, agreeing only to an "investigation" of King's notion.[37] This was not enough for Fisher. In July 1915 the Admiral told BIR's members they should not be "facile dupes" or "servile copyists"; instead, they should "initiate" and act with "daring Nelsonic bravado." Fisher, taking King's axial flow suggestion under his wing, commanded the BIR to locate Britain's best pump designer for King's experiments, and demanded workable pumps be ready within three weeks. Assigned an office and a draftsman, King was joined by a Mr. Franklin of the Worthington-Simpson Pump Company. Axial flow pump technology was "almost unknown at the time," and Franklin doubted the mechanism could achieve fifty per cent efficiency. Once the design was done, King, sent to Scotland to install the pumps on a submarine reluctantly provided by the BIR in September 1915,[38] found the submarine's tail shaft was ten inches higher than expected; thus, the pump would not fit between the shaft and the hull. King devised a technical solution, only to have the BIR's naval secretary, Sir Richard Paget, tell him that the BIR had decided on 5 October to opt for a system, designed by Parsons, of propellers mounted outside the hull on vertical shafts. When King pointed out that a similar design had failed years before, Paget was blunt; "We are advised by the best scientists and engineers in England and we take their advice, good day Mr. King."[39]

When Parsons's scheme failed in December 1915 – the BIR phrased the verdict gently to assuage the influential Parson[40] – an ungracious Paget gave King another chance. Worthington-Simpson required three months to produce a suitable pump with 34- to 44-per cent unit efficiency. Having not forgiven King's criticism of Parson's design,

36 Minutes of the BIR's Central Committee, 23 September, 1915, ADM293/7, TNA; Guy Hartcup, *The War of Invention: Scientific Developments, 1914-18* (London: Brassey's, 1988), p. 141; BIR report, "Vickers Battleship Design," 15 October 1915, Ibid. ADM293/6, TNA; Professor B. Hopkinson, "Report on the Protection of Ships against Torpedo Attack," 21 October 1915, Ibid.; and King, "Autobiography," p. 7.

37 King, "Autobiography," p. 8; and BIR Central Committee minutes, 26th August 1915, ADM293/7, TNA.

38 Memorandum of meeting of the BIR's Sub-Committee of Section II, 14 September 1915, ADM293/5, TNA.

39 King, "Autobiography," p. 9; Fisher cited in Jack K. Gusewell, "Science and the Admiralty During World War I: The Case of the BIR," in Gerald Jordan, ed., *Naval Warfare in the Twentieth Century, 1900-1945: Essays in Honour of Arthur Marder* (London: Croom Helm, 1977), p. 107; and memorandum of meeting of the BIR's Sub-Committee of Section II, 5 October 1915, ADM293/5, TNA.

40 E.B. Tod, M.W. Burgess, and F.F.P. Bisacre, "Control of Submarine by Vertical Propellers," 12 December 1915, ADM293/6, TNA.

Paget forbade King personally to install the mechanism. After King's assistant, Burgess, ran into trouble, he and King convinced Lord Northwood, acting in Paget's absence, to authorize another trip to Scotland for King. When Northwood subsequently blocked King's journey in July 1916, the RN's Chief Constructor ordered King to install the pumps. It took until November to work out the bugs, and drag still absorbed one third of the vessel's horsepower at surface speed.

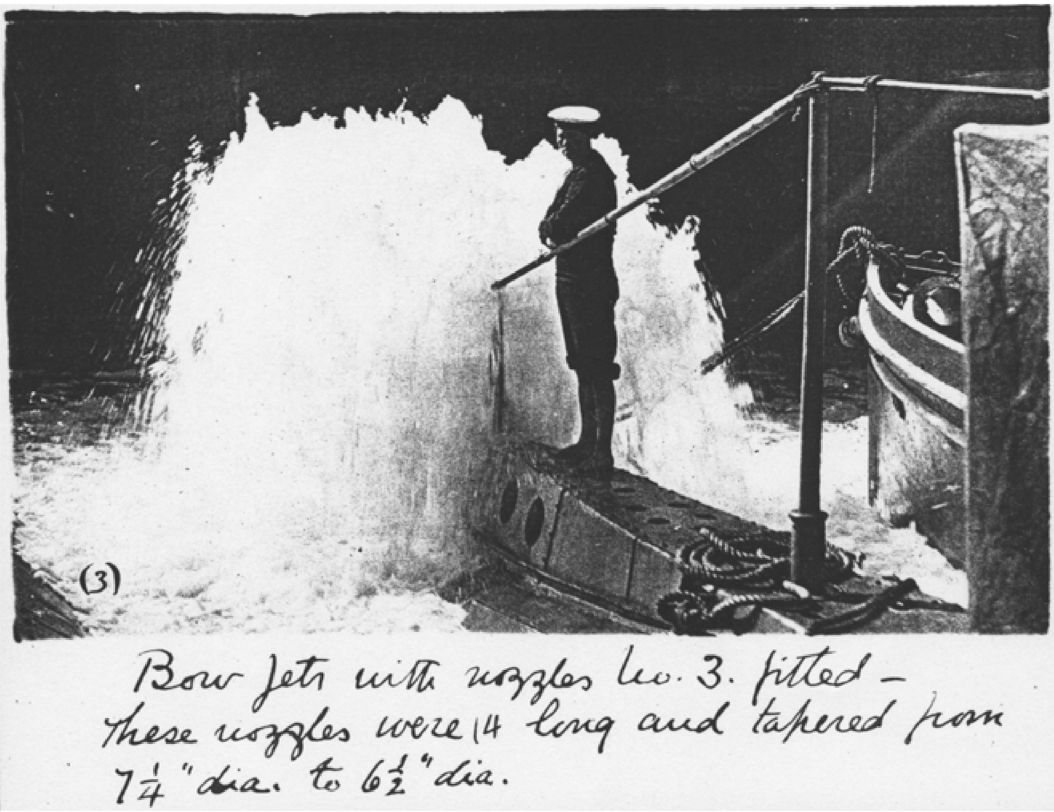


*Illustration 3: Bow of Submarine A10, showing King's Water Jets Installed to Provide Depth Control (1916). Courtesy: Mrs F.R.B. King.*

The BIR had in fact long since all but rejected King's project, and would not renumerate him for his submarine work. In the spring of 1916 the board had referred King's concept to the Royal Society's Engineering Committee for further investigation.[41] Charles H. Merz, who had judged King's axial flow design, stated that not only had the BIR not asked King to undertake his propulsion research, King "had made claims and calculations that he had not been able to substantiate." The BIR also decided in April 1916 to close its correspondence with King on the subject, ruling his original proposal

41 King, "Autobiography," p. 9; memorandum of meeting of the BIR's Sub-Committee of Section II, 7 December 1915, ADM293/5, TNA; Charles H. Merz, "Report on Depth Control of Submarines," 4 April 1916, ibid.; BIR Central Committee minutes, 4 May 1916, ADM293/7, TNA.

had been withdrawn while King's modified proposal was "not novel to the Admiralty." King, however, obtained four patents from the work, including one that is essentially the predecessor of the propulsion system now used in the "jet-ski" type of personal water-craft.[42]

After consulting briefly for a boiler manufacturing company, King joined the Royal Flying Corps (RFC) in February 1917 with the rank of second lieutenant,[43] a level he thought disappointingly junior. He tested devices designed to reduce aircraft noise, work that took him to air bases and manufacturing facilities throughout Britain. Callendar, now a Physics professor at Imperial College, upon discovering that King's "office" constituted of a desk at the new Royal Air Force (RAF) headquarters in London, offered him laboratory space at Imperial College. It was a fortuitous shift as Imperial College had an "outstanding" reputation for scientific contributions to Britain's war effort.[44] Further, King's maritime technical skills were in demand as German submarines were exacting such a terrible toll on shipping that Britain's survival was in doubt. Over 14,000 anti-submarine suggestions were made to British authorities. Some were ridiculous, including training seagulls to land on submarine periscopes! That idea was rejected, but the BIR experimented with the training of sea-lions to find submerged craft.[45] Callendar's own project was to measure magnetic anomalies using long antennae trailed behind surface vessels, a not entirely original idea as an RN officer, Captain C.A. McEvoy, had suggested in 1882 that magnetic induction coils might be disturbed by the steel hulls of nearby submarines. The idea had been revived early in the war, but in 1915 the BIR ruled that sound detection methods "were superior." According to Callendar, his approach, presented to the BIR in December 1917, was superior to hydro-phone sound detection as that method likely could not detect a stationary submarine.[46] Knowing King's

42 Memorandum of the meeting of the BIR's Sub-Committee of Section II, 18 April 1916, ADM293/5, TNA; King, "Improvements in and relating to Jet Propulsion for Aquatic Vessels," UK Patent N° 103,325, awarded 19 January 1917; King, "Improvements in and relating to Submersible Vessels," UK Patent N° 108,411, awarded 9 August 1917; and King, "Improvements in and relating to Submersible Vessels," UK Patent N° 15,718, awarded 20 March 1919; and King, "Submarine Boat," US Patent N° 1,017,103, awarded 13 February 1912.

43 Robert Owen King Service Record, 1917-1920, Air Ministry Officers' Service Records, AIR76/277, TNA. Claiming he was offered a captaincy in 1916, King demanded that rank in 1917 but was turned down. He agreed to take the lower rank when the RFC officer who inducted him said "that promotion in the RFC was very rapid for anyone who deserved it"; King, "Autobiography," p.10.

44 Hartcup, *The War of Invention*, p. 190.

45 Richard Compton-Hall, *Submarines and the War at Sea* (London: Macmillan, 1991), pp. 94-97.

46 Willem Hackmann, *Seek & Strike: Sonar, Anti-Submarine Warfare and the Royal Navy 1914-54* (London: Her Majesty's Stationery Office, 1984), p. 7; memorandum of the BIR's Sub-Committee of Section II, 5 October 1915, ADM293/5, TNA; and Professor H.L. Callendar, "Electromagnetic Method of Indicating a Moving Ship the Relative Position of a Submerged Submarine and of Following the Submarine if it is Moving in Any Direction," 26th December 1917, ADM293/10, TNA.

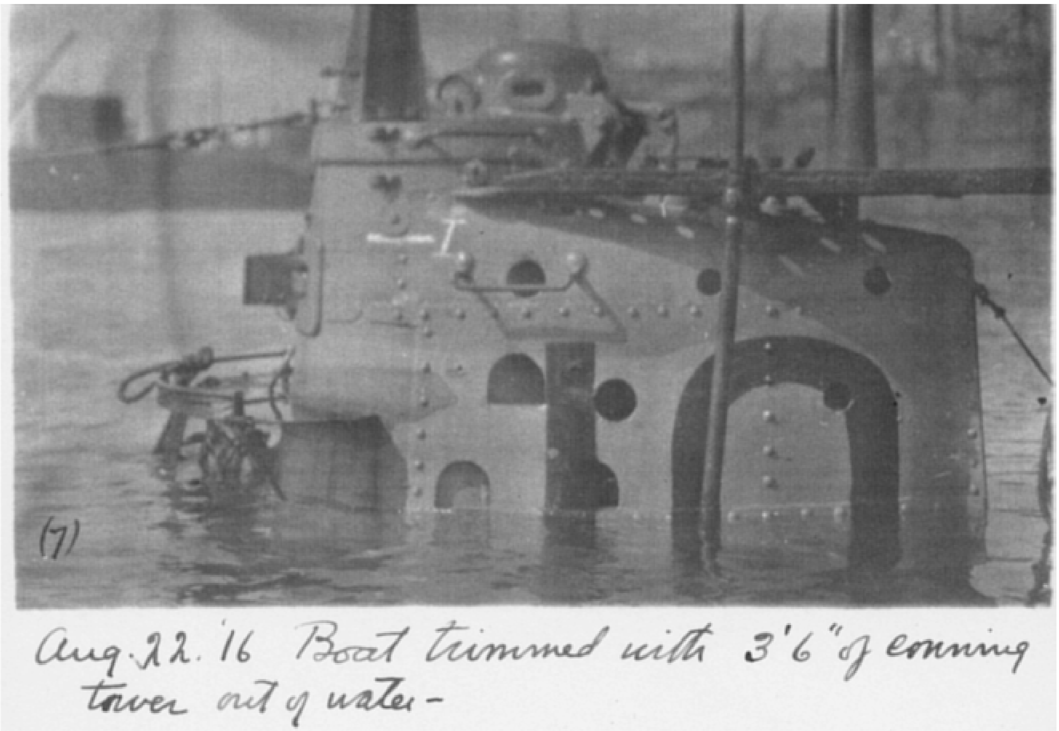


*Illustration 4a: Conning tower of submarine A10, without the King jets in operation. Courtesy: Mrs F.R.B. King*

practical abilities, Callendar gave him responsibility for the work. King, hospitalized for three weeks by a shrapnel injury suffered during a German air raid on London, sent an assistant to Portsmouth to install the mechanism on a destroyer with help from a scientist from the RN's Harwich Anti-Submarine Station. Unfortunately, the device worked only in calm water, a rare condition in the tempestuous Atlantic; BIR experts also found the mechanism's effective range extremely limited even under ideal conditions.[47] In the end it was good tactics rather than technical devices that defeated the submarine offensive. The Admiralty, in the spring of 1917, adopted the ancient technique of sailing merchant ships in convoys escorted by warships and, in coastal waters, by aircraft. The submarines had enormous difficulty finding convoys, and even when they did, they could not attack aggressively for fear of exposing their positions.

## 5. Engine Research at the (UK) Air Ministry

After a temporary transfer to the Ministry of Munitions in May 1918, in August King returned to the Air Ministry. Days before the Great War's end, the Air Ministry hired him to run its Engine Test Plant at Imperial College. King's decision to abandon

47 King, "Autobiography," p. 12; and appendix, "Electro-magnetic Detection of Submarines," attached to the memorandum of preliminary meeting of the BIR Sub-Committee of Section II, 4 December 1917, ADM293/11, TNA.

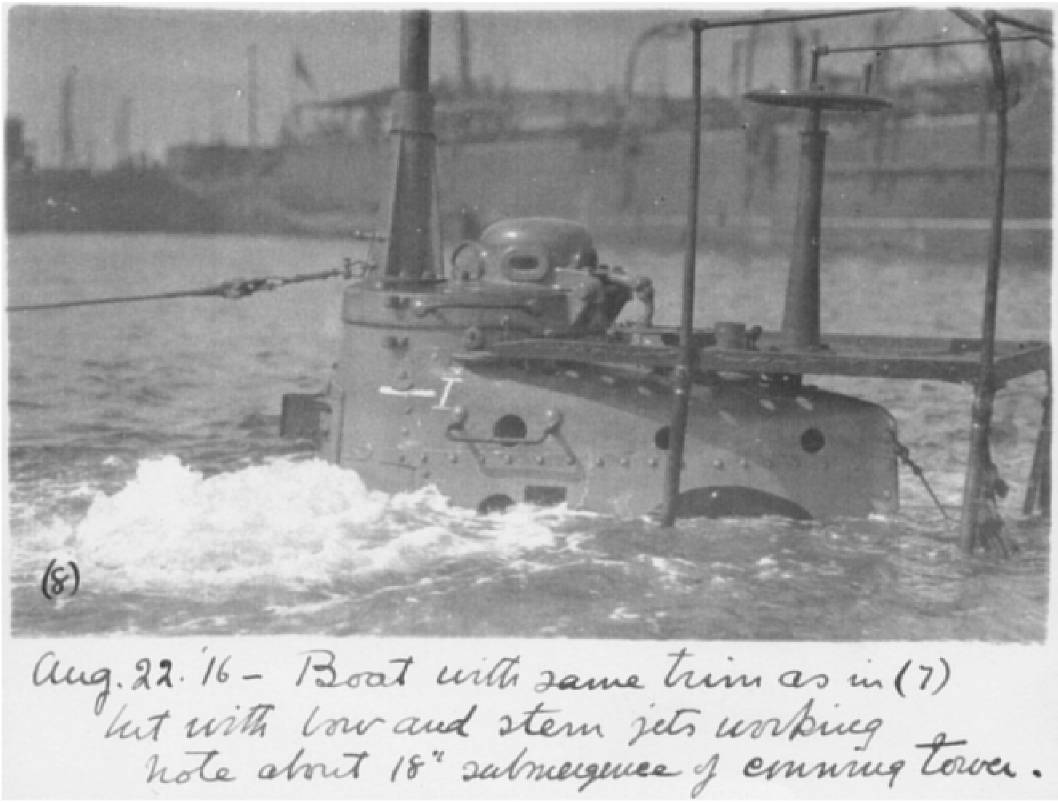


*Illustration 4b: Conning tower of submarine A10 with the King jets on and holding the boat submerged an additional 60 cm (1916). Courtesy Mrs F.R.B. King*

naval research is easy to understand given his unpleasant BIR experience. Not even Fisher's personal support for his axial flow idea could save it. This was unsurprising as the mercurial Fisher had been named head of the BIR because the Cabinet deemed it more "advantageous" to have Fisher within the government than free to critique official policy. Fisher's championing of King's axial flow design, coming as it did after Parsons's plan had failed, earned King few friends within the BIR. Nor were King's problems unique. The investigation in 1917 of the BIR's charges of insufficient support from the Admiralty by a committee under Sir Southern Holland noted that while the RN initially welcomed the BIR, the navy thought "pure science is essentially impractical. The needs of the service are essentially practical." The results could be bizarre as BIR sonar specialists were denied access by the Admiralty to the anti-submarine facilities at Harwich in 1917.[48] Aviation research also seemed more promising. In the words of the American historian Joseph Corn, "like the Christian gospels, the gospels of aviation held out a glorious promise, that of a great new age in human affairs once airplanes brought

48 Gusewelle, "Science and the Admiralty During World War I," pp. 106 and 110-111; MacLeod and Andrews, "Scientific Advice in the War at Sea," p. 28; and Guy Hartcup, *The Challenge of War: Britain's Scientific and Engineering Contributions to World War Two* (New York: Taplinger, 1970), p. 21.

about a true air age." As a visiting American Aviation Mission concluded in 1919 that Britain led the aviation world, London was the place to be for an ambitious Canadian engineer.[49]

Still, many problems remained. Malcolm Cooper maintains that Britain's inability to produce sufficient warplanes until 1917 created much of the poisonous rivalry between the RFC and the Royal Naval Air Service that had prompted their merger into the RAF. The war's welcome end did not stop the bureaucratic infighting, and the "senior services" made several attempts to dismantle the RAF. The government, moreover, cut military spending significantly after 1925. With no obvious foe, a massive war debt, and a burgeoning pacifist movement, political leaders sought a peace dividend.[50]

King's concern was the often tenuous existence of his research laboratory in the face of dwindling resources and heightened competition for those resources. In December 1918, recognizing Imperial College's contribution to the war effort, the RAF transferred its Engine Test House to the College on condition that the facility continued to carry out weapons and equipment research for the RAF.[51] By 1924 that laboratory, led by H.E. Wimperis, reported to the Air Ministry's Directorate of Scientific Research. An idealist, in 1932 Wimperis publicly stated that "the benefits to be enjoyed from any discovery, that of human flight for instance, turn less upon its mechanical perfection, however splendidly satisfying to the engineer, than upon the dreams and ideals of those who are able to guide its destiny and guards its use."[52] The directorate, however, had real world problems. First, as Maurice Hankey, the powerful secretary to the Cabinet, declared in November 1919, the Air Ministry should abolish or reduce all "Branches not actually engaged in operative administration, e.g. statistics, publicity, liaison, intelligence, returns and reports."[53] The directorate faced chronic budgetary shortages, while the Air Staff, refusing to relinquish control over weapons research, emphasised improving existing systems, not true innovation. Unsurprisingly, the directorate had trouble recruiting civilian scientists.[54]

King's engineering skills suited him ideally to undertake the careful experimental work needed to advance the embryonic understanding of the processes occurring during

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49 Joseph Corn, *The Winged Gospel: America's Romance with Aviation, 1900-1950* (New York: Oxford University Press, 1983), p. 27; and Peter Fearon, "The British Airframe Industry and the State, 1918-35," *The Economic History Review* vol. 27 (May 1974), p. 236.

50 Malcolm Cooper, "Blueprint for Confusion: The Administrative Background to the Formation of the Royal Air Force, 1912-19," *Journal of Contemporary History* vo. 22 (July 1987), p. 446; and John Robert Ferris, *Men, Money, and Diplomacy: The Evolution of British Strategic Foreign Policy, 1919-1926* (Ithaca: Cornell University Press, 1989), pp. 172-175.

51 Secretary of the Air Council W.A. Robinson, "Air Ministry Laboratory Post War Policy," 3 December 1918, Air Council Minutes and Memoranda Records, AIR6/19, TNA.

52 Wimperis cited in Ronald W. Clark, *The Rise of the Boffins* (London: Phoenix House, 1962), p. 13.

53 Maurice Hankey to Secretary of the Air Ministry, 20 November 1919, AIR6/20, TNA.

54 Pattison, "The Munitions Inventions Department," p. 557; and M. Kirby and R. Capey, "The Air Defence of Great Britain, 1920-1940: An Operational Research Perspective," *Journal of the Operational Research Society* vol. 48 (1997), p. 559.

combustion in a spark ignition engine. He settled in as an Air Ministry researcher, with no shortage of technical issues to keep him busy. In 1923, King produced his first scientific publication since the century's turn. Dealing with one of the necessities of an engine test cell – the air flow measurement system – his paper on the design and construction of an air box and orifice plate for this purpose highlighted King's distinctive comprehensiveness and practicality. He systematically laid out guidelines and specific instructions for building and using an air box and orifice plate, which he called a "throttle plate,"and provided tables to simplify the required computations. He also concocted pragmatic rules of thumb on such matters as the expected airflow (about 1 gram/second of air per each horsepower produced by the engine), and techniques for avoiding or correcting air leakes in the equipment.. A number of practical tips for sources of supply for less common materials and fluids needed, calibration method of the equipment, and the level of accuracy that might be expected, made the paper a comprehensive manual for practitioners. This was the working style of a meticulous experimentalist able to winnow tiny kernels of accurate test data from bushels of conflicting engine results. King published another instrumentation paper in 1924,[55] describing his production and calibration of equipment based on one of Callendar's ideas. While many scientists used hot-wire anemometry techniques, Callendar's novel contribution involved a modification that allowed a broad range of air-flows to be measured with a single instrument. This development facilitated repeatable, accurate and consistent readings, and, as in the case of the air flow measurement equipment, King's paper provided a thorough description of a working implementation of the Callendar device, including set-up instructions, a calibration method and expected accuracy.

In 1925, after Wimperis complained about a lack of results from the test house, King got his permission to spend £2500 on an early variable compression ratio research engine, a Ricardo E35. It allowed compression ratio to be varied from 3.8 to 7.5, amusingly low values by modern standards, but perfectly adequate then because fuels could not be run at higher compression ratios without unacceptable knock levels. The need for basic research was illustrated by the example of American experience that aviation engines running well on one coast of the country would unaccountably knock violently on the opposite coast. Since the only apparent difference was that nominally equivalent aviation fuels came from different crude oil sources, scientists inferred that chemical structure differences were responsible. Fuel quality then was based primarily on volatility, there being no known method to characterise fuel knock resistance. Nor were relationships between chemical structure and combustion performance understood. The physical and chemical mechanisms for knock remained mysterious and subject to speculation and competing theories. Virtually all the techniques still used for characterising fuel combustion behaviour emerged during this period, but advances were accompanied by confusion, false starts and dead ends. Indeed, the din of high powered engines under test was exceeded only by the clangor of clashing egos.[56]

55 R.O. King, "The Measurement of Air Flow by Means of a Throttle Plate with Special Reference to the Measurement of the Air Supply to Internal Combustion Engines," *Engineering* (13 and 20 April 1923), pp. 56-458, and 481-482.

56 R.O. King, "The Callendar Hot Wire Anemometer," *Engineering* (1 and 22 February 1924),

Knock, the greatest enigma facing interwar engine researchers, occurred when engines were under heavy loads, especially at low operating speeds, under high pressures required by supercharged aero-engines or if cylinders were too large. Briefly, the flame initiated by the spark plug propagates through the fuel/air mixture inside the cylinder, producing a rapid but controlled rate of pressure rise. At any moment, that portion of the mixture through which the flame has not yet passed was nevertheless being compressed and heated continuously by the combustion going on in the burning part of the mixture. Under knocking conditions, the heated and compressed "end gas" (the unburned portion of the cylinder contents) spontaneously ignites, resulting in undesirable pressure waves and a rapid rate of pressure rise. Both thermal and mechanical damage can quickly ensue if the condition persists. Knock is the fundamental limiting process in a spark ignition engine, so early researchers sought to understand its causes and means to suppress it. The Air Ministry was vitally concerned given its need for higher powered engines for its warplanes. King's staff had to investigate the performance of various fuels as well as the fuel additives, referred to as "dopes," that might suppress knock. The most important dope was tetra-ethyl lead, the most effective and practical compound for the suppression of knock as determined by extensive testing carried out by T.J. Midgley and T.A Boyd in America.[57] Small amounts of this additive produced remarkable improvements in conventional fuel knock resistance. Gasoline doped with tetra-ethyl lead allowed the engine to run at higher compression ratios and heavier loads with substantially greater maximum power and improved fuel economy. The additive also produced deleterious cylinder deposits and engendered mystifying results since small amounts gave dramatic improvements but larger amounts aggravated rather than suppressed knock.

Better understanding of the mechanisms at work were needed best to employ additives. Knowledge about how the knocking and pre-ignition processes were triggered, the physical and chemical mechanisms involved, and the influence of fuel molecular structure remained nebulous. Callendar joined the theoretical fray in 1925 with a proposed mechanism for knock initiation called the "Nuclear Theory of Ignition." Unsatisfied with the accepted notion that spontaneous ignition occurred entirely within the gaseous phase, Callendar believed spontaneous ignition also took place when very small fuel drops were present. Through thermodynamic reasoning, he showed that heavy components of the fuel blend could remain as droplets or re-condense under high pressures inside the cylinder. These minute drops would persist in the mixture, acting as "foci of ignition" for two reasons: they would contain mostly heavy hydrocarbon compounds having a lower ignition temperature; and also because of the preferential heating through absorption of radiation energy from the flame. Solid smoke particles produced in the early combustion phase, Callendar reasoned, could act as condensation nuclei as they concentrated within the droplets and increased radiation absorption. Ignition would occur as a heterogeneous reaction at the droplet/gas interface. Using his nuclear theory, Callendar also explained the mechanism whereby metallic dopes such as

pp 136-137 and 249-251.

57 See Stuart W. Leslie, "Thomas Midgley and the Politics of Industrial Research," *Business History Review* vol. 54 (Winter 1980), pp. 480-503.

tetra-ethyl lead suppressed knock. As the metal component was known to condense out of the gas phase, he postulated this would tend to coat the drops with a metallic skin. Since such drops were only a minute fraction of the total fuel present, small amounts of dope, thanks to their low volatility, might have been effective as they tended to concentrate within the drops responsible for knock.[58]

King began a program in 1928 to investigate if fuels would or would not tend to produce nuclei, thereby testing the nuclear drop theory. King's interest in hydrogen thus began.[59] As hydrogen fuel lacks carbon, there would be no smoke particles, no nuclear drops and hence no knock. Hydrogen was added therefore to King's test matrix. Callendar's theory and later developments such as the influence of organic peroxides on knock were rejected by other researchers, including Imperial College colleagues. Fate then intervened again for King. After Callendar's death in 1930, his successor at Imperial College desired King's laboratory for other projects. King, displaced to the London City & Guilds College, found the Air Ministry had lost interest in his work. Making matters worse, the Great Depression forced budget cuts. King was compulsorily retired, ostensibly due to age, in 1934.[60] Before retirement, King experimented using gases flowing through tubes as a means of studying the effects of drops, dusts and x-rays on the ignition of combustible gases, experiments he described in seven papers.[61]

58 H.L. Callendar, R.O. King, and C.J. Sims, "Dopes and Detonation," *Engineering* vol. 121, (9, 16, 23 and 30 April and 21 May 1926), pp. 475-476, 509-511, 542-545, 575-576 and 605-608; and H.L Callendar, R.O. King, E.W.J. Mardles, W.J. Stern, N.R. Fowler, "Dopes and Detonation," *Engineering* (4, 11 and 18 February 1927), pp. 147-148, and 182-184.

59 King's interest in hydrogen as a fuel may have been sparked by the BIR's wartime experiments with hydrogen; see minutes of the BIR Central Committee Board of Inventions and Research, 10 August 1916, ADM293/7, TNA.

60 King, "Autobiography," p. 12.

61 R.O. King, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear Drops of Water and Other Nuclei and by X-Rays. Part I. The Explosion of Gaseous Combustible Mixtures Passing Through Vitreous and Steel Combustion Tubes, by Nuclear Drops of Water," *Journal of the Institution of Petroleum Technologists (JIPT)* (August 1934), pp. 791-805; R.O. King, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear Drops of Water and Other Nuclei and by X-Rays. Part II. The Explosion of Hydrogen-Air Mixtures by X-Rays," *JIPT* (August 1934), pp. 806-812; R.O. King, and G. Mole, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear drops of Water and Other Nuclei and by X-Rays. Part III. The Explosion of Hydrogen-Air Mixtures by Stone Dust," *JIPT* (August 1934), pp. 812-815; R.O. King, and G. Mole, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear Drops of Water and Other Nuclei and by X-Rays. Part IV. The Explosion by Nuclear Drops of Water of Ethylene-Air Mixtures Passing through a Nickel-Steel Combustion Tube," *JIPT* (August 1934), pp. 816-820; R.O King, and G. Mole, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear Drops of Water and Other Nuclei and by X-Rays Part V. The Experimental Conditions required for the Ignition of Hydrogen-Air Mixtures by Nuclei,"*JIPT* (October 1935), pp. 838- 845; R.O. King and G. Mole, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear Drops of Water and Other Nuclei and by X-Rays. Part VI. The Nuclear Drop Ignition Temperatures of Ethylene-Air Mixtures Passing Through a Silica combustion Tube; The relation between Wall and Gas Temperature and the Effect on Ignition Temperatures of the

King did not remain unemployed long; his reputation as a meticulous researcher saw to that. In addition to papers related to knock and detonation,[62] his work on engine lubrication issues[63] brought him eight patents for engine exhaust silencers, carburettors and bearings.[64] Retirement at 60 held few charms for such an energetic man. When Cambridge University offered him space, money, and graduate students in Professor Ideal's Colloid Science Laboratory for fuel research, King agreed. His research soon drew the attention of Standard Oil and General Motors in America.[65]

## 6. World War II: Naval R&D

King remained immersed in engines and fuels research at Cambridge during the first nine months of the Second World War. He then returned to Canada for what he termed "family reasons" in the summer of 1940. R.O. King's timing, again, was fortuitous. His homecoming roughly coincided with the Tizard Mission's arrival in

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Central Thermocouple Sheath," *JIPT* (October 1935), pp. 845-853; and R.O. King and G. Mole, "The Explosion of Mixtures of Combustible Gases with Air by Nuclear Drops of Water and Other Nuclei and by X-Rays Part VII. The Effect of a Variety of Nuclei, Mainly Mineral Dusts, to Ignite and Explode a Mixture of Hydrogen and Air; The Exceptional Efficacy of $Ni_2O_3$ Dust to Ignite Mixtures of Air with Hydrogen, Ethylene or Methane," *JIPT* (October 1935), pp. 853-859.

62 R.O. King and H. Moss, "The Measurement of Detonation in Internal-Combustion Engines," *Engineering* (23 and 30 August 1929), pp. 219-221 and 272-274; R.O. King and H. Moss, "Detonation and Lubricating Oil,"*Engineering* (11 and 25 July 1930), pp. 31-33 and 99-101; R.O. King and H. Moss, "Detonation as Affected by Mineral Lubricating Oils", *Engineering* (2 January 1931), pp. 1-4; R.O. King and H. Moss, "Detonation, Spark Plug Position and Engine Speed,"*Engineering* (7 August 1931), pp. 177-180.

63 R.O. King, "The Beneficial Effect of Oxidation on the Lubricating Properties of Oil," *Proceedings Royal Society, (London)* vol. 139 (February 1933), pp. 447-459; R.O. King and C. Jakeman, "Lubrication in Oxidising Conditions," *Aeronautical Research Committee, R&M Series* no. 1517, (January 1933); R.O. King, "The Effect of Metallic (Lead) Dope on the Carbonisation of Oil in the Combustion Space of an Engine," *Engineering* (25 August 1933), pp. 183-186; and R.O. King, "Oxidation Lubrication and the Blending of Mineral Oils to Obtain Maximum Lubricating Value," *JIPT* (February 1934), pp. 97-137.

64 King, "Improvements in Silencing Devices for the Exhaust Gases of Internal Combustion Engines," UK Patent N° 223,327, awarded 23 October 1924; King, "Improvements in and relating to Fish Tails or like Devices for the Exhaust Pipes of Internal Combustion Engines," UK Patent N° 259,017, awarded 7 October 1926; King, "Improvements in or relating to Carburetting Apparatus for Internal Combustion Engines," UK Patent N° 278,425, awarded 5 October 1927; H.L. Callendar, R.O. King, and E.W.J. Mardles, "Improvements in or relating to Lubricating or like Oils," UK Patent N° 295,230, awarded 7 August 1928; King, "Exhaust Pipe Tailpiece", US Patent N° 1,607,003, awarded November 16, 1926; King, "Method of Carbureting Air," US Patent N° 1,724,942, awarded 20 August 1929; King, "Silencing Devices for the Exhaust Gases of Internal Combustion Engines and the Like," Canadian Patent N° 254380, issued 6 October 1925; King and Mardles, "Preparation of Bearing Surfaces," Canadian Patent N° 341186, issued 24 April 1934.

65 King, "Autobiography," p. 13.

Canada. Recently appointed to head Britain's scientific war effort, Sir Henry Tizard came to North America to seek aid and encourage more military research in Canada.[66]

The 66 year-old King became the "Examiner of Naval Inventions" for Canada's National Research Council. NRC's origins lay in the Great War. After Britain created a committee to foster scientific and industrial research in 1915, the Colonial Office recommended similar bodies for the Dominions. In November 1916, Canada set up the Honorary Advisory Committee for Scientific and Industrial Research, with representatives drawn from scientific, technical, and industrial interests although the NRC undertook no laboratory work until 1925. In 1932, the NRC opened a central laboratory building in Ottawa, and had five divisions by 1936 – Physics and Engineering, Biology and Agriculture, Chemistry, Research Information, and Mechanical Engineering. In 1939 the NRC had one lab, an annual budget of $900,000, and 300 employees. Once the enormity of the scientific and industrial effort this new conflict would demand was clear, the NRC took on that mandate. By war's end, the NRC had 2,000 scientific and technical researchers, led by its able acting President, C.J. Mackenzie, with a budget in the millions.[67]

No belligerent can ignore creative solutions that might offer it a technological edge over its enemies. Mackenzie knew this well; by March 1940, 80 percent of NRC activities were war-related.[68] Seeking to emulate the BIR, on 25 October 1939, officials present at a meeting of the British Supply Board and the Canadian War Supply Board in Ottawa discussed forming an agency to deal with "the large numbers of inventors who always came forward with ideas under circumstances like the present." Immediately, Wallace Campbell of the Canada's War Supply Board asked the NRC to be that agency; Mackenzie accepted two days later. One month later, Mackenzie proposed a Board of Inventions – an examining committee with three technical specialists, a consulting panel drawn from specialists in relevant government departments, universities, or other bodies, and the board itself, possibly six "senior members of the Department of National Defence, War Supply Board and the Research Council" – within the NRC. The board would "examine inventions, ideas, technical proposals, etc., pertaining to weapons, warfare, munitions, materials, production, etc., submitted the Dept. of National Defence and War Supply Board." It would reject "impracticable and unsound proposals," and "assess the value of promising ideas, place them before the appropriate government organization and, at the request of the organization, arrange for the testing and

66 Ibid.; and David Zimmerman, *Top Secret Exchange: The Tizard Mission and Scientific War* (Montreal & Kingston: McGill-Queen's University Press, 1996). The notion of a war of limited liability is discussed in J.L. Granatstein, *Canada's War: The Politics of the Mackenzie King Government, 1939-1945* (Toronto: University of Toronto Press, 1990). King may have returned to Canada in 1940 to care for his aged mother; interview conducted with Sandy Allen by Bardon, 29 April 1999.

67 Wilfrid Eggleston, *Scientists at War* (Oxford University Press, Toronto, 1950), pp. 9-13; and D.J. Goodspeed, *A History of the Defence Research Board of Canada* (Ottawa: Queen's Printer, 1958), pp. 5-8.

68 C.P. Stacey, *Arms, Men and Governments: The War Policies of Canada 1939-1945* (Ottawa: Department of National Defence, 1970), p. 507.

development of the ideas."[69]

Persuaded, Cabinet issued Privy Council Order PC239 on 24 January 1940. Mackenzie would chair a three-man Inventions Board, with Wallace and National Defence's Acting Deputy Minister, to oversee the Examining Committee and Consulting Panel. Introduced by an NRC press release on 12 March, the board promised "adequate attention" to every suggestion for while many proposals will already have been investigated, "there is always the possibility that one outstanding discovery may come to light, the adoption of which will have far-reaching effects in the prosecution of the war."[70] By mid-February, as Mackenzie told Wallace, the board's Consulting Committee – a physicist, a chemist, and a mechanical engineer – was examining over 400 invention proposals. Mackenzie had high hopes for the board, which, he wrote on 1 March "brings us directly in contact with all the government departments from the Prime Minister's Office down."[71]

How King came to the board's attention is unclear. King's autobiography states simply that after "being unable to get a return passage to England" in 1940, he became the NRC's "Chief Examiner of Inventions." The Invention Board's official report for 1941 remarks only that King was one of the Examining Committee's "active members."[72] Given King's patents and extensive engineering experience, he was ideally suited to judge the practicality of the schemes offered by enterprising Canadian inventors. King had to separate the "wheat from the chaff," and there was no shortage of chaff. As the minutes from the consulting panel's first meeting noted in April 1940, it was seriously perusing just 30 of the 1,300 individual communications sent to the Board. By 1941's end, the board was inundated by 8,128 proposals.[73]

King abruptly left the Inventions Board in the spring of 1942 to become the "Examiner of Naval Inventions" (ENI) in the RCN's newly-established Naval Research

69 H. Hooper, Assistant Secretary British Supply Board, to Mr. Lecky, Secretary War Supply Board, 29 December 1939, plus extract of first weekly meeting of the British Supply Board and the War Supply Board, 25 October 1939, Invention Board Records, RG121, vol. 113, file 44-1-28 vol. 1, LAC; W.R. Campbell to C.J. Mackenzie, 25 October 1939, Ibid.; Mackenzie to Campbell, 27 October 1939, ibid.; and Mackenzie to Campbell, 21 November 1939, ibid.

70 Privy Council Order PC239, 24 January 1940, ibid.; and "Inventions Board Established by Government," 12 March 1940, ibid.

71 Mackenzie to Wallace, 16 February 1940, Ibid,; Mackenzie to A.G.L. McNaughton, 18 January 1940, in Mel Thistle, ed., *The Mackenzie-McNaughton Wartime Letters* (Toronto: University of Toronto Press, 1975), pp. 14-15; and Mackenzie to McNaughton, 1 March 1940, ibid., p. 22.

72 King, "Autobiography," p. 13; and S.J. Cook, Secretary Inventions Board, "Report to the Inventions Board for the Year Ended 31 December 1941," 9 January 1942, Department of National Defence Records, RG24, vol. 4056, file NSS1078-12-32, LAC.

73 Minutes, 1st meeting of the Consulting Panel, 15 April 1940, RG24, vol. 4056, file NSS1078-12-32, LAC; "Report to the Inventions Board for the Year Ended 31 December 1941," 9 January 1942, RG24, vol. 4056, NSS1078-12-32, LAC; and "Government Tells What You Should Not Invent," *Science News Letter*, 2 October 1942, p. 219.

Section. The reasons for this shift are obscure. King's "Autobiography" notes only he "transferred to the same job in the R.C.N." The invention board's report of May 1942 offered a different interpretation; King had "resigned."[74] Bureaucratic battles likely forced King's decision. David Zimmerman's study of the RCN's technological problems during the Second World War notes that the navy was "the least committed" of the three services "to a program of scientific research conducted" at the NRC thanks to a complacent reliance upon the RN for navy technical needs and a failure to recognize the value of new technologies such as radar. Not until 30 December 1940 did the RCN accept the NRC as its official scientific establishment, responsible for all research and scientific liaison.[75] The NRC soon had naval technical groups at Vancouver, Ottawa, and Halifax, but cooperation between the navy and the council left much to be desired. Mackenzie's meeting with Commodore H.G. DeWolf in July 1945, for example, marked "the first time that any senior officer in the RCN had ever discussed details of research and development with anybody at the Research Council."[76]

The creation of King's new position in fact was the result of the failures in cooperation. On 8 May 1942, Captain G.M. Hibbard, the RCN's chief of naval equipment and supply, announced that King's position would relieve various branches from "the onerous task of replying to inventors, and, moreover, allow of more complete examination of each new idea" by funnelling submissions to one official. All naval proposals formerly submitted to the NRC Inventions Board now had to go to King. Mackenzie responded that this seemed a good idea if the intention was to provide additional information and advice to the Inventions Board. If, however, the RCN, objecting "to the entire set up of the Inventions Board," wanted the board to pass on correspondence to the ENI for final disposal, this "radical change in an arrangement set up by an Order in Council" could compel Mackenzie "to call the Board together and discuss the matter." Hibbard, whose 8 May letter had stated the handling of naval inventions was "open to criticism," responded on 23 May that it was not his "intention to criticize the general scheme of the Inventions Board." However, the "Examining Committee, as now constituted, should not undertake the responsibility of whether an invention may or may not be useful to the naval service, or even whether it should or should not be submitted to Naval consultants" as Mackenzie had offered. To solve this problem, Hibbard wanted King to see all NRC invention files before the Invention Board acted. If an invention was recommended for development, the board must transfer all subsequent correspondence to the RCN. Finally, King should gain access to all relevant NRC records, contained in the council's "13-Series" files. Mackenzie told Hibbard on 6 June the examining committee did not judge submissions as "useful or applicable"; that job belonged to consulting panel's specialists. While Hibbard's second request departed "somewhat from our original instructions," the NRC chief said the ENI could judge the proposals. As for King acquiring NRC invention files, Mackenzie dug in. While "there

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74 King, "Autobiography", p. 13; and Cook, "Inventions Board: Report for the Month of May, 1942," 2 June 1942, RG24, vol. 4056, file NSS1078-12-32, LAC.

75 David Zimmerman, *The Great Naval Battle of Ottawa* (Toronto: University of Toronto Press, 1989), pp. 10-13 and 36-37.

76 Ibid., pp. 37 and 148.

would be no difficulty in the Examiner of Naval Inventions obtaining copies of all documents required," the NRC could not "throw open its filing system to the officers of another department." Nor would it transfer essential project documents from the Inventions Board.[77]

King likely had instigated this contretemps. On 5 February 1942, Lieutenant J.R. Millard, the Navy's research liaison officer (RLO) to the NRC, had informed the RCN's Technical Division that King, and S.J. Cook, the Inventions Board's secretary, would "be responsible, so far as technical matters are concerned, to the President of the Inventions Board" (Mackenzie). On the left margin, dated 11 June 1942, King noted that "Dean Mackenzie agreed to this memo on condition that I withdraw my resignation from the Ex. Cttee. The agreement was verbal. Mr. Cook did not act in accordance with the memo and stated that he had not agreed to it." King took Mackenzie's letters of 15 May and 6 June badly. Claiming the "tone" of those missives indicated that Mackenzie (or more likely Cook) was "unwilling to modify the provisions of the Order in Council relating to the Inventions Board," King recommended dropping the matter unless it was deemed sufficiently important to discuss at a specially convened Inventions Board meeting. Significantly, King questioned the qualifications of H.V. Haight, his replacement on the examining committee. Haight was a University of Toronto engineering graduate once employed as a design engineer and invention scout, but King noted that he "has had no Naval or Mercantile experience." Moreover, no Examining Committee member possessed "the qualifications required to decide what inventions should or should not be passed to Naval Consultants for advice." King, however, was unconcerned by Mackenzie's refusal to hand over the NRC's 13-series invention files. King could get around that prohibition via Millard and the NRC's naval liaison officer, Dr. D.C. Rose.[78]

The matter remained contentious. On 8 July 1942, Hibbard asked Mackenzie to ensure that all "correspondence relating to inventions of possible interest to Naval Service" should now be sent directly to the Naval Board's secretary rather to any divisional heads. The secretary then would give the material to the ENI to ensure the submissions would pass "into the hands of one person" without overlapping. On 18 July, Cook tersely replied "This request has been noted and action taken accordingly." Three days before, after discovering that an invention proposal from a Toronto citizen had gone

77 Captain G.M. Hibbard to Mackenzie, 8 May 1942, RG24, vol. 5590, file NSS10-39-6, LAC; Mackenzie to Hibbard, 15 May 1942, RG24, vol. 4056, file NSS1078-12032, LAC; Hibbard to Mackenzie, 23 May 1942, ibid.; and Mackenzie to Hibbard, 6 June 1942, 6 June 1942, ibid. There is a discrepancy about when King took up his RCN position. In his 1948 application to the DRB, King said his start date was April 1942. According to naval records, King took up the job in mid-May 1942; King, "Defence Research Board Application Form," 7 May 1948, Civil Service Board Records, RG32, vol. 328, file 1874-10-17 King Robert O., LAC; and Secretary Naval Board, memorandum 57, "Inventions," 14 May 1942, RG24, vol. 5590, file NSS10-39-6, LAC.

78 Lieutenant J.R. Millard to the Director of Technical Division RCN, 5 February 1942, plus marginal comments by King, 11 June 1942, ibid.; and King to Chief of Naval Equipment and Supply, "Letter dated June 6th, from Dean Mackenzie, re relations between E.N.I. and Inventions Board," 11 June 1942, ibid.

initially to King, Cook complained that all communications with naval applications must be channelled through the Inventions Board first. In turn, the Board would send such material to King via Millard, who after consulting naval experts, would submit his recommendation to the Examining Committee through Millard. An irate King charged in November 1942 that 24 NRC files dealing with naval inventions had been "dealt with by the Inventions Board without consulting" the RCN first. Only six files were handled satisfactorily, two replies to inventors disclosed confidential information, four showed "ignorance of current developments," nine were uninformed, while three offered unnecessary discussion.[79]

Millard, a University of Toronto engineering graduate and former NRC worker in the early 1930s, had few warm feelings for his former employer. In February 1942, Millard opined that the December 1940 NRC-RCN agreement ill-served the navy as the NRC was a "public institution" created to do research for all government departments and commercial organizations. The NRC could "never be a perfectly satisfactory Naval research organization since it is not under naval control" and navy research too often was not a priority for the NRC given its many other obligations. Millard offered two radical solutions. First, the navy's RLO, not Mackenzie or Rose, should select the most suitable organization for any research project. Second, the navy should replace NRC laboratories with its own research/experimental department. As David Zimmerman points out, Millard's suggestion carried weight. In the spring of 1943 the navy abandoned the NRC deal to form its own Directorate of Technical Research (DTR) led by Millard.[80] The Inventions Board was reconstituted in May 1943, with a new Naval Consulting Committee (NCC) controlled by the RCN. Led by Millard and King, the new committee would appraise naval inventions put forward by naval personnel and seek opinions from senior naval technical officers regarding naval inventions submitted by civilians or other military personnel.[81]

The creation of the NCC and DTR appeared to signal the navy's victory over the NRC. Appearances were deceiving. On 22 July 1943, describing the 1940 agreement with the NRC as "a temporary expedient," Millard assailed Mackenzie for not defending navy interests in his dual roles as NRC president and director of scientific research (DSR) for the navy. Proclaiming the DSR was only "a figurehead" who lacked "the confidence of the Naval Staff group," Millard commented Britain's Admiralty, a crucial source of technical and scientific information, "has been rather loath to take the NRC completely into its confidence in the matter of providing up-to-date information and reports." He proposed eliminating the DSR position and its deputy, letting the DTR's director act as the RCN's research representative, appointing a naval officer to head the DTR as it could be difficult to remove an unsatisfactory civilian incumbent, asking the Admiralty to send

79 Hibbard to Mackenzie, 8 July 1942, ibid.; Cook to Hibbard, 18 July 1942, ibid.; Cook to Doris L. Bentley, Private Secretary to the Minister of Naval Services, 15 July 1942, ibid.; and King to Senior Technician Technical Division RCN, 17 November 1942, ibid.

80 Zimmerman, *The Great Naval Battle of Ottawa*, pp. 63-64 and 150-151.

81 L.R. Thomson, Secretary Inventions Board, to W.G. Mills, Deputy Minister of Naval Services, 6 October 1943, RG24, vol. 4056, file NSS1078-12-32, LAC.

reports directly to the RCN rather than the NRC, and expanding Halifax's facilities to form the basis of a "full scale research laboratory for the future." Mackenzie agreed that the "desirable" establishment of the DTR and the other aspects of the reorganization had prompted "better cooperation and coordination of scientific relations between our Departments." Nor did he oppose scrapping the DSR and deputy posts "as the officers holding these positions have never really functioned in the capacity indicated by the title." Mackenzie insisted the NRC should remain the RCN's official research establishment and wished to appoint a liaison officer to the DTR to replace the DSR position.[82]

The navy, however, rejected the liaison officer, a proposal Mackenzie let die. On 1 January 1944 the RCN took over the NRC's Halifax research station, but Millard's hopes for an enhanced navy research program foundered as the Halifax facility never became a major research organization; the NRC remained "the pre-eminent centre for Canadian naval scientific research and development for the rest of the war." Further, eight officers strong in April 1944, the DTR's lack of direct access to the Naval Board hindered planning, while other RCN technical directorates often denied the DTR any role in their activities.[83] Nor was the Inventions Board imbroglio resolved. In January 1944, Millard and King complained that the Inventions Board was treading on the NCC's bailiwick by granting patents to naval inventions submitted by navy personnel. The Inventions Board should deal only with submissions from civilians. L.R. Thomson, Cook's replacement, cited Privy Council orders to state bluntly that the Board had the "responsibility" to examine "all inventions and suggestions made by members of the Armed Forces." Thomson advised that if the RCN properly constituted its NCC, held regular meetings, and kept minutes regarding all suggestions and inventions submitted by naval personnel, NCC's members would be recognized as part of the Inventions Board; in this way, "both the intent and letter of the regulations will be fully met."[84]

By mid-1944 King, as Millard' successor as director of technical research, had new concerns. On 28 September he recommended changing his title to director of scientific research and development as that phrasing would better match British and American organizational nomenclature. A week later, he requested two new positions, a deputy director research and a deputy director development. The former position, "not urgent at present," should go to a person with "high scientific attainments and a special knowledge of at least one important subject." The latter office, "an urgent necessity," was

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82 Millard to the Deputy Director of Warfare & Training and the Assistant Chief of the Naval Staff, 22 July 1943, RG24, vol. 8166, file NSS1700-10/53, LAC; and Mackenzie to Secretary Naval Board, 26 July 1943, RG24, vol. 5590, file NSS10-39-6, LAC.

83 Zimmerman, *The Great Naval Battle of Ottawa*, pp. 153-154. The limits placed upon the DTR are noted in Assistant Chief of the Naval Staff memorandum, 22 May 1944, RG24, vol. 8166, file NSS1700-100/53, LAC; and Commander E.G. Cullwick, "Terms of Reference DTR," 20 September 1944, ibid.

84 King memorandum, 10 January 1944, RG24, vol. 4056, file NSS1078-12-32, LAC; A.B. Coulter to Mills, 13 January 1944, ibid.; Secretary Naval Board to Mills, 7 January 1944, Ibid.; and Thomson to Mills, 24 January 1944, ibid.

required to plan and expedite development undertaken by the directorate's officers. Commander D.L. Raymond, director of warfare and training, approved the position for a deputy director development. Raymond ruled that "there is insufficient research in hand to justify getting in another scientist as D.D.R.," althought such a position would be important "for a post-war set-up."[85]

## 7. Post World War II: Canadian Defence Research Board

On 28 September 1945 King complained that his staff – three scientists and "a number" of officers – was to be reduced to a female librarian and a reserve officer, a staff level "insufficient to carry on the work of the Directorate." While he recognized that "long term commitments to civilian staff cannot be made at present and to carry over until the post war research organization is established," he hoped to obtain at least one more military researcher.[86] King got the military researcher but could expect nothing more until a postwar military research organization was formed. The overwhelming impact of scientific and engineering advances on the war's prosecution made military authorities cognizant of the need to retain postwar active research and development programs.[87]

The need to retain new capabilities very much concerned Canadian officials as the war wound down. Mackenzie warned that if Canada's scientific corps was disbanded, the nation again would become "an exporter of scientific brains and an importer of the products of our exported genius."Canada's Chiefs of Staff (COS) concurred. On 24 July 1944 they informed the Cabinet War Committee (CWC) that as "any future war would involve even greater recourse to scientific devices...research related to wartime problems should continue in times of peace as well as in time of war."[88] On 28 March 1947, Parliament amended the Department of National Defence Act of 1927 to create the Defence Research Board. Its head was Dr. O.M. Solandt, a Canadian physician who had served as an operations research scientist in the British forces during the war, ultimately becoming South East Asia Command's chief scientific adviser.. Solandt would coordinate the military's research activities, liaise with the NRC and other agencies, survey research facilities, make organizational recommendations, and undertake any scientific duties the minister of national defence might request...[89]

The DRB absorbed *ad hoc* wartime research and development organizations and

85 King to R.L. Raymond, 28 September 1944, RG24, vol. 8166, file NSS1700-100/53, LAC; King to Raymond, 4 October 1944, ibid.; and Raymond to King, 14 October 1944, ibid.

86 King to Raymond and Coulter, 28 September 1945, ibid.

87 Stacey, *Arms, Men and Governments*, p. 512; and Donald H. Avery, *The Science of War: Canadian Scientists and Allied Military Technology during the Second World War* (Toronto: University of Toronto Press, 1998), pp. 260-261.

88 Mackenzie cited in Goodspeed, *A History of the Defence Research Board of Canada*, p. 13; and Chiefs of Staff (COS) to the Cabinet War Committee (CWC), document 829, "Committee on Research for Defence," 24 July 1944, Cabinet War Committee Records, RG2 7c, vol. 16, LAC.

89 Goodspeed, *A History of the DRB*, pp. 21, 33-35, 40-43, 59-60, and 65-67.

established its headquarters in Ottawa. King, having seen his tenure as at Naval Headquarters end in April 1947, King transferred to the DRB's Naval Section in 1948 as one of its first scientists. He was then 74 years of age. Solandt wanted King to act as deputy director scientific research and development for nine months so that he "may complete certain research, of Naval interest, which he has undertaken." There is little doubt why King, despite his age, had been retained. Solandt wrote to a South African colleague in May 1947 that the DRB's "greatest problem is certainly going to be getting well-qualified people." Canada faced shortages of trained scientists but with universities expanding, Solandt hoped shortages would be "temporary." Still, Solandt's first annual report admitted recruitment had suffered because scientists were hesitant "to work for the Government, and especially for an agency which does secret work"; the DRB also suffered from "considerable doubt regarding its permanence."[90] Had King intended to leave the DRB? At the DRB's first meeting on 16 April 1947, Solandt, defending his decision to retain King to complete ongoing projects, stated that King "wished to retire." However a March 1947 memorandum, signed by King, indicates King had engineered the short term contract.[91] When King joined the DRB, public servants did not face compulsory retirement. So, when a mandatory retirement age of 65 was introduced in the 1950s, King should have stopped working. However, his DRB superiors obtained annual extensions for King by submitting memoranda to the Privy Council, explaining his work's importance. For example, in March 1950, when King was 76, Solandt's submission noted that he was "an international authority on the subject of internal combustion engines." The minister of national defence, Brooke Claxton, personally relayed the request to the Treasury Board, which subsequently exempted King from mandatory retirement rules.[92]

King, who carried out combustion research specializing in the oxidation of engine fuels, prospered at the DRB. His salary in 1943 was $3,600 per annum. By March 1948, he earned $5,000, which rose to $8,450 in 1953.[93] And he quickly made

90 O.M. Solandt to Chief of the Naval Staff, "DSRD and Naval Scientific Adviser to DGDR," 27 March 1947, RG24, vol. 8166, file NSS1700-100/53, LAC; Solandt, "Policy and Plans for Defence Research in Canada," 3 May 1946, RG24, vol. 11995, file 1-0-43-1, LAC; Solandt to B.J. Schonland, 2 May 1947, RG24, vol. 4243, file Corres. with BJ Schonland May2/47, LAC; and "Annual Report of the Chairman, Defence Research Board," 16 September 1948, RG24, vol. 11995, file 1-0-43-1, LAC.

91 Minutes, 1st meeting of the DRB, 16 April 1947, RG24, vol. 11996, file 1-0-43-2, LAC; and King memorandum, 5 March 1947, RG32, vol. 328, file 1874-10-17 King, Robert O., LAC.

92 Solandt to MND Brooke Claxton, 21 March 1950, RG32, vol. 328, file 1874-10-12 King, Robert O, LAC; Claxton to the Treasury Board, 22 March 1950, ibid.; and Privy Council Order PC80/1784, 5 April 1950, ibid.

93 King memorandum, 5 March 1947, RG32, vol. 328, file 1874-10-17 King, Robert O., LAC; "Salary adjustments recommended for the scientific and administrative staff of the Defence Research Board," Annexure A to minutes, 6th meeting of the DRB, 19 March 1948, RG24, vol. 11996, file 1-0-43-2, LAC; minutes, 17th meeting of the DRB, 6-9 December 1950, Ibid.; and "King, Robert Owen," 17 August 1955, RG32, vol. 328, file 1874-10-12 King, Robert O, LAC.

connections. Professor A.E. Allcut, head of the University of Toronto's Mechanical Engineering Department, knew King's pre-war combustion work. He made laboratory facilities available to King who provided technical direction and arranged DRB funding for the university's engine research, mostly dealing with the pre-ignition and knock behaviour of various fuels and the mechanisms responsible for the observed behaviour. King commuted from Ottawa to Toronto to supervise a team of researchers and graduate students. According A.B. Allan, a team member, while King was a good researcher, he could not lecture, was reluctant to write things down, and only informed the DRB of his activities after their completion, thus guaranteeing success.[94]

King had begun his hydrogen work in the mid 1920's, an era of great foment in combustion engine research. Engine technology had advanced thanks to wartime needs for high power aircraft engines. However, combustion behaviour in spark ignition engines displayed unexplained anomalies. The requisite understanding of the underlying physical and chemical mechanisms responsible for important combustion effects such as pre-ignition and knock in spark ignition engines did not exist. Carefully controlled tests and reliable data thus were essential, and King, above all, was an experimentalist. King's original hydrogen work was initiated merely to provide a test fuel containing no carbon, inspired by Callendar's nuclear drop theory. That theory is now a superceded scientific curiosity, but by obtaining high quality experimental evidence, King constructed an impressive foundation of sound data related to hydrogen. Although undertaken to understand knock in gasoline engines, his hydrogen experimental work demonstrated hydrogen's unusual characteristics as a spark-ignition engine fuel in its own right, and how to control those peculiarities. King's conclusions about hydrogen's sensitivity to hot spots such as spark plugs, exhaust valves, deposits or particles clarified the behaviour of this unusual fuel and guide work even now. This was not serendipity but a result of years of painstaking, carefully crafted experiments, often designed deliberately to provoke pre-ignition, flashback and knocking combustion, so as to better study the phenomena concerned.

King conducted tests in specially designed combustion tube apparatus to examine closely the details of hydrogen's combustion behaviour. The tests demonstrated that hydrogen ignition could be triggered by the presence of small water drops,[95] X-rays,[96] "stone dust" (alumina),[97] and other incombustible metallic oxides, sulfides and sulfates.[98] Both electrical and catalytic influences of the particles were mooted as potential

94 Goodspeed, *A History of the DRB*, p. 213; and Allan interview, 29 April 1999.

95 King, "The Explosion of Mixtures....Part I, *Journal of the Institution of Petroleum Technologists* (August 1934), pp. 806-812; and King and Mole, "The Explosions of Mixtures... Part V," *Journal of the Institution of Petroleum Technologists* (October 1935), pp. 838-845.

96 King, "The Explosion of Mixtures...Part II," *Journal of the Institution of Petroleum Geologists*, (August 1934), pp. 806-812.

97 King and Mole, "The Explosion of Mixtures...Part III," *Journal of the Institution of Petroleum Geologists* (August 1934), pp. 812-815.

98 King and Mole, "The Explosion of Mixture...Part VII," *Journal of the Institution of Petroleum Geologists* (October 1935), pp. 853-859.

explanations for the surprising effects of materials which, in themselves, offer no obvious chemical reaction mechanisms to ignite hydrogen/air mixtures. King's experimental results were published in 1948.[99] Researchers had failed to achieve satisfactory combustion in hydrogen-fuelled spark ignition engines. Flashback in the induction system, knocking and pre-ignition plagued virtually all earlier work in this area, preventing the use of all but lean mixtures and very low compression ratios. As the fuel economy and power achieved under these limitations were unsatisfactory, hydrogen was considered impractical to fuel such engines. King demonstrated these combustion problems were neither inevitable nor unavoidable; rather, the causes lay in the sensitivity of hydrogen to ignition by hot combustion chamber surfaces and particles. He showed that excessively hot spark plug ceramic cores, hot exhaust valves, and the presence of carbon deposits or particles from the lubricating oil produced these effects. By installing cooler mechanical components and removing chamber deposits, he was able successfully to run without combustion problems over the entire flammable range of fuel/air ratios, and at compression ratios up to the highest possible in the Co-operative Fuel Research engine that he used for the original tests, namely 10:1. He subsequently showed that similar results could be obtained running on town gas rich in hydrogen, another problematic engine fuel; if one could eliminate the hot surfaces or particles responsible, combustion would be satisfactory.[100]

King also demonstrated that lubricating oil penetration into the combustion chamber at the levels typical of the engines of the time led to the recurrence of the combustion problems due to carbon particles resulting from the decomposition of the lubricating oil at the high temperatures in the chamber. He proved that periodic physical cleaning or burn-out of chamber deposits solved the problem, as did better oil control through changes in the piston rings. King also enlarged the data set and showed that compression ratios as high as 20 could be used with hydrogen,[101] achieving an indicated thermal efficiency of 46.5 percent at a compression ratio of 12. He also added to the literature on the sensitivity of hydrogen to ignition from the effects of small particles by reporting knocking combustion caused by ingesting cement dust, powdered charcoal and even cigarette smoke into engine air intakes.[102] This experimental *tour de force* legitimised all subsequent work on hydrogen as a fuel for spark ignition engines by overturning the conventional wisdom that it could not be done. King paved the way for a generation of hydrogen researchers whose interest blossomed after the oil embargo of

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99 R.O. King, W.A. Wallace, and B. Mahapatra, "The Oxidation, Ignition, and Detonation of Fuel Vapors and Gases V. The Hydrogen Engine and the Nuclear Theory of Ignition," *Canadian Journal of Research* vol. 26 (1948), pp. 264-276.

100 R.O. King, W.A. Wallace, and B. Mahapatra, "The Oxidation, Ignition, and Detonation of Fuel Vapors and Gases VI. The Prevention of Pre-Ignition and Detonation in Gas Engines," *Canadian Journal of Research* vol. 26, (1948), pp. 366-373.

101 R.O. King et ses collaborateurs, "Le moteur à hydrogène," *Revue de l'Institut français du pétrole* vol. XIII, No. 4, (Avril 1958), pp. 577-585.

102 R.O. King, S.V. Hayes, A.B. Allan, R.W.P. Anderson, and E.J. Walker, "The Hydrogen Engine: Combustion Knock and Related Flame Velocity," *Transactions of the Engineering Institute of Canada* vol. 2, no. 4, (December 1958), pp. 1-6.

1973-74 and the crippling energy crisis it engendered in the industrialised world.[103]

## 8. Conclusions

King's career ended in 1959, the victim of bureaucratic considerations rather than any slackening on King's part. First, the DRB opted to hand over its Combustion Research Section to the University of Toronto by 1 July even though the DRB's Chief Scientist noted in September 1958 that the University could not "exert full technical direction" over the section for another two years. As King "is still very active and is continuing to be responsible for the large research output of the Combustion Group at the University of Toronto," the chief sought to retain King's services during this interim period. King was retained, while in April 1959, the DRB recognized that the University of Toronto still could not take over technical direction of the Combustion Group as that program had been for so long "a development of Mr. King's own ideas." G.S. Wright of the DRB's Directorate of Personnel feared this request might require the chairman's or the vice-chairman's direct intervention as the Treasury Board had called him the previous year "to question" King's extension.[104] The vice-chairman declined to help. Arguing King's staff had "enough knowledge, experience, and ideas" to continue the research, he asserted "we must not forget that it falls to the younger generation to retire at 65." Although not suggesting "King has lost any of his remarkable scientific staying power," he worried the DRB would appear "somewhat lacking in judgement if we press this already most exceptional case into yet another year." Professor G. Ross Lord, Allcut's successor, offered a solution. As the university was "not yet in a position to relinquish the overall supervision of Mr. King," the university should keep King on for another year as the money "would not be large." King, already a university special lecturer, agreed with a proviso that his lecturer salary not be covered by a new contract that transferred $65,000 per annum for five years from the DRB to support the university's Combustion Group. King expected to spend four or five days a month in Toronto, his travel costs to be covered by the contract. King had space at the DRB's Ottawa headquarters, as well as part-time secretarial assistance and library and technical aid.[105]

On 5 November 1959, the DRB announced King's retirement after "nearly 65 years of full-time scientific research." Presiding over a small ceremony, DRB chairman Dr. A.H. Zimmerman described King as the "driving force" in combustion research, adding that King's studies of high energy fuels for military purposes was "especially interesting." At age 85, King was awarded the Plummer Medal of the Engineering

103 See L.L. Das, "Hydrogen Engines: A View of the Past and a Look into the Future," *International Journal of Hydrogen Energy*, vol. 15, no. 6, (1990), pp. 425-443.

104 Directorate of Personnel DRB memorandum, "Note for Files," 3 April 1958, RG32, vol. 328, file 1874-10-12 King, Robert O, LAC; G.S. Field, Chief Scientist DRB, memorandum, "Mr. R.O. King," 16 September 1958, Ibid.; Field to Directorate of Personnel, "Mr. R.O. King," 16 April 1959, Ibid.; G.S. Wright memorandum, "Extension of Employment to Age 86 R.O. King," 20 August 1959, ibid.

105 Vice Chairman DRB memorandum, "Extension of Employment to Age 86 R.O. King," 24 August 1959, ibid.; G. Ross Lord to A.H. Zimmerman, DRB Chairman, 7 March 1960, ibid.; Field to Lord, 28 March 1960, ibid.

Institute of Canada for the best paper published by the institute that year. Recognizing his lifetime achievements, the Ontario Branch of the American Society of Mechanical Engineers gave him the Allcut Award in 1965.[106] King died in 1966, in his 92nd year. During his 65-year-career he showed a keen interest in a wide variety of scientific and technical subjects, and made considerable contributions in greenhouses, ship salvage, submarines, engines, lubricants, and instrumentation. He is now remembered primarily for laying the groundwork for practical hydrogen engines. Virtually all of King's work was motivated by practical engineering issues. A contemporary of Harry Ricardo, Roy Fedden and other early engine researchers, his scientific contributions, notably 31 patents and 58 technical papers, constitute a large body of results from meticulous experimentation, the majority on fuel behaviour. Like many Canadian professionals of his generation, King left Canada to pursue his interests and make a living. In doing so, he amassed immense experience and established a considerable reputation among his peers and the broader practical scientific community. After decades away, he returned to a country which, undergoing its own development odyssey, badly needed his talents. Another Canadian scientist and practical engineer of wide interests, Sir Sanford Fleming, had a man like R.O. King in mind when he said that while engineers were "not as a rule gifted with many words," they "must plod on in a distinct sphere of their own, dealing less with words than with deeds, less with men than with matter."[107] R.O. King was an engineer who mattered.

106 DRB press release AFN49-59, 5 November 1959, received from Dr. Donald King; and A.H. Wilson, Engineering Institute of Canada, to Bardon, 9 December 1999.

107 Sanford Fleming quoted in Millard, *The Master Spirit of the Age*, p. 12.