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Laboratory Cultures

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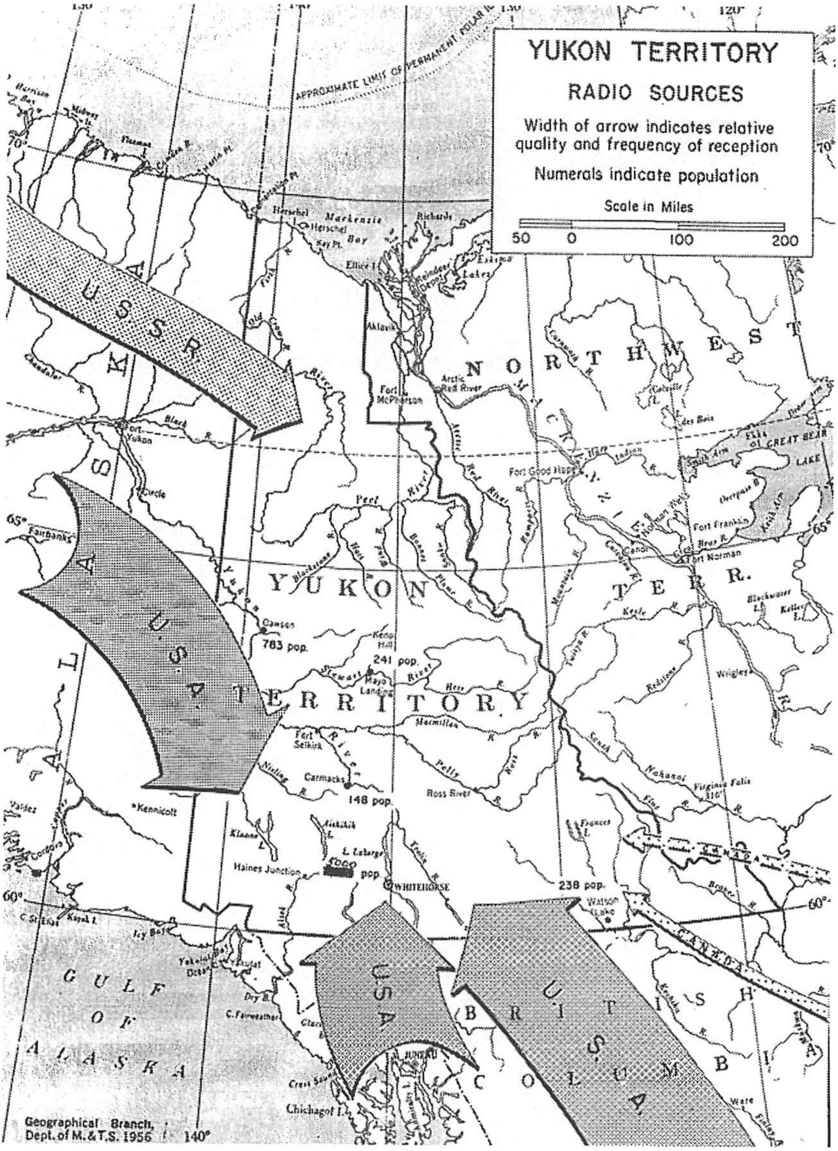
Article abstract

This essay uses the visual and material cultures of two laboratories as a way of initiating an historiographical discussion about what it means to write the history of science and technology in Canada. It uses a potentially familiar topic—the conception and construction of the Alouette satellite—to illustrate how the discipline might shed its self-conscious preoccupation with discoveries and innovations, and instead focus its attention on a revised exploration of the question: what is Canadian about Canadian science and technology?



A map showing the reception quality of radio broadcasts in the North, along with the source of the transmissions (1953). The Alouette project was designed to overcome situations like this through the production and analysis of the visual records known as ionograms. Note the arrows marked "Canada" near the lower right corner.

Source: National Archives of Canada, Canadian Broadcasting Corporation Record Group 41 (hereafter NAC, RG 41), vol. 127, file 5, part 2, F.H. Collins, "Radio in the Yukon Territory: A Brief Presented to the Royal Commission on Broadcasting," April 1956, 4-5.

Laboratory Cultures

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Résumé: Cet essai se sert des cultures visuelles et matérielles de deux laboratoires afin d'engager une discussion historiographique sur ce que signifie écrire l'histoire de la science et de la technologie au Canada. Il emploie un sujet potentiellement familier, la conception et la construction du satellite Alouette, pour illustrer la façon dont la discipline pourrait se défaire de sa préoccupation consciente pour les découvertes et les innovations et se concentrer plutôt sur une exploration révisée de la question : qu'y a-t-il de canadien dans la technologie et la science canadiennes ?

Abstract: This essay uses the visual and material cultures of two laboratories as a way of initiating an historiographical discussion about what it means to write the history of science and technology in Canada. It uses a potentially familiar topic—the conception and construction of the Alouette satellite—to illustrate how the discipline might shed its self-conscious preoccupation with discoveries and innovations, and instead focus its attention on a revised exploration of the question: what is Canadian about Canadian science and technology?

There is metaphysics in our histories. In the subjects we interrogate, in the questions we pose, in the answers we seek, we make crucial presumptions about the nature of science, the essence of technology, and the character of historical processes. We privilege institutions over individuals, politics over practices, mathematics over material cultures. We alternate between continuities and ruptures, failures and successes, innovation and stasis; and we use these distinctions to argue about what could have been, what should have been, and what never was. Yet all too often we take for granted the assumptions of our craft. We ignore alternate histories, different modes of interrogation that question how we treat the relationships between knowledge and nation, nature and artifice, technology and culture. And in doing so, we deny ourselves the opportunity to speak to wider concerns in the history of science and technology, to address deeper and less self-indulgent questions: What kinds of histories might science and technology have? How do we begin writing about the interrelations between natures, humans, and machines?

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In what follows, I am interested in one such alternate history. It interests me not as a source of simple and ready answers to complex questions, but as a means of helping to launch a long-overdue discussion about the historiography of Canadian science and technology.[1] The subject may be familiar: On 29 September 1962, at 06:05 hours, amid a string of upper atmospheric nuclear tests and growing cold-war tensions, the U.S. National Aeronautics and Space Administration launched a modified ballistic missile from the Pacific Missile Test Range in California. Its payload consisted of a 145-kilogram satellite designed and built by the Canadian Defence Research Telecommunications Establishment (DRTE), a defence research organization made up of three research laboratories—the Communications Laboratory, the Radio Physics Laboratory, and the Electronics Laboratory—and located just northwest of Ottawa along the Ottawa River. The project's goal was to study the portion of the upper atmosphere known as the ionosphere for a period of one year. At a time when satellites regularly failed after only months in orbit, the Alouette satellite (known by the codename S-27 before its launch) would continue sending its vital data through radiation disturbances and meteorite impacts for a period of ten years.

Historical accounts have since seen the satellite in various guises—as scientific instrument, as industrial prototype, as cold-war status symbol.[2] But no image of the object, or of the project that created it, has been as pervasive as the one that places Alouette at the beginning of a technological trajectory leading inevitably to communications satellites, and therefore to reliable national telecommunications. The satellite stands as a powerful symbol of innovation and success, but above all, as a symbol of technological integrity in a nation that has long equated reliable communications with national identity and cultural survival.[3]

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[1] Don MacLeod has argued that this debate has been a long time coming. See "A Maturing of Purpose: Recent Publications in the History of Technology and the Physical Sciences in Canada," *Acadiensis* 20 (1990): 225-243.

[2] See, for example, Doris H. Jelly, *Canada: 25 Years in Space* (Montreal: National Museum of Science and Technology, 1988); Theodore R. Hartz and Irvine Paghis, *Spacebound* (Ottawa: Government of Canada, Department of Communications, 1982); R. E. Barrington, "Canadian Space Activities in the Past Quarter Century," *Canadian Aeronautics and Space Journal* 25 (1979): 153-69.

[3] For two examples of the often implicit way Alouette has been written into the history of communications satellites, see Robert Babe, *Telecommunications in Canada: Technology, Industry, and Government* (Toronto: University of Toronto Press, 1990), 221-222; and Bert C. Blevis, "The Pursuit of Equality: The Role of the Ionosphere and Satellite Communications in Canadian Development," in *Beyond the Ionosphere: Fifty Years of Satellite Communications*, ed. Andrew J. Butrica (Washington, D.C.: NASA History Office, 1997), 195-203.

For all their value in pointing to the future significance of Alouette, accounts like this form part of a mode of history that I want to suspend for a moment. Specifically, I want to question the way these histories constitute their subject. Because they take communication satellites as their endpoint, these histories trace what we might call the 'stable technologies' of the satellite—thermal blankets, telemetry transmitters, solar cells, antennas—the technical features common to a wide range of satellites, features that transcend any one satellite's immediate purpose. In homogenizing the string of Canadian satellites running from Alouette to Anik, they ignore the complex and sometimes conflicting ideas, practices and priorities that attended each device. More seriously, the accounts are rooted in a kind of technological determinism that I would like to avoid.[4] Here, machines and engineers, institutions and politics, funding schemes and lab directors furnish the gears and springs of a clockwork world; their actions lead us inevitably through an unproblematic technological succession from scientific instruments to communication satellites. But the laboratories in which Alouette was imagined, designed and built become interesting only for their contributions to a series of extraordinary machines that would finally realize the dream of reliable nationwide communications.

What, then, if we changed our focus? What if we situate the satellite not within the narrow continuum of technological family resemblances to which it has been ascribed, but instead within the complex and evolving scientific, instrumental and engineering traditions that conceived and constructed it? What if we see the satellite not as what it will become, but as what it was meant to be—a generator of crucial scientific images shot through with issues of national identity and integrity, and the politics of the Cold War? The immediate goal of the satellite project that produced Alouette was to generate what were arguably the most important inscriptions of upper atmospheric physics in the 1950s and 1960s—the graphic records known as ionograms. These images, standing between the interests of ionospheric physics and radio engineering, were crucial to the Canadian post-war projects of national sovereignty and identity. Before satellites ever promised to extend reliable communications to the Canadian North, ionograms stood as the best guarantors of an integral nation. A material and cultural history of the ionogram, then, is what we are after. We have to make the ionogram central if we want to grasp why

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[4] For a more general discussion of technological determinism, see Donald MacKenzie, ed., *The Social Shaping of Technology*, 2nd ed. (Philadelphia: Open University Press, 1999), 3-6; and Merrit Roe Smith and Leo Marx, eds., *Does Technology Drive History?: The Dilemma of Technological Determinism* (Cambridge: MIT Press, 1994).

producing these images from a satellite was *crucial* rather than incidental. The satellite is still important here, but it must form part of a longer tradition of visual representations in upper atmospheric research rooted in the technological priorities and the emerging material culture of the Cold War.

Without cutting the issue too thin, then, I want to focus on *S-27* rather than on *Alouette.* In doing so, I want (perhaps counterintuitively) to decentre a number of historical objects that have been privileged until now—the satellite itself, its seemingly phenomenal successes, and the Communications Laboratory responsible for proposing it. Instead, I would like to focus on the cultures of DRTE's other two laboratories—the Radio Physics Laboratory, whose work had relied for a decade on the ionogram and the information it provided, and the Electronics Laboratory, which would engineer and partly construct the artifact. There are thus two moves that we want to perform. First, we need to locate the satellite within an ionogram-based visual culture rooted in the Radio Physics Laboratory; and secondly we want to see the satellite as part of a reliability-based material and engineering culture, rooted in transistor electronics and advanced weapons systems, which dominated the work of the Electronics Laboratory. The standard story severs the satellite from both of these traditions. In reconnecting it to the practices and concepts that produced it, the satellite becomes the occasion to explore these two laboratory cultures and to see what they can tell us about how we might approach the historical study of science and technology in Canada. If we shift our attention away from the obvious outer technology of the satellite to focus instead on its graphic products and the technologies that produced them, the laboratories of DRTE emerge as the sites of astonishing cold-war debates over the relations between knowledge and nation, nature and artifice, humans and machines. They give us insight not only into the history of Canadian science and technology, but into the broader realms of Canadian history and of science studies writ large. In order to begin engaging those larger spheres, however, we need to push into the places of physics and engineering in order to see what the act of producing ionograms meant for DRTE, and how the anxieties over the production and integrity of those records were partly addressed through the visual and material culture of war.

Laboratory Cultures

Over the last two decades, the history of science has begun examining the social and cultural functions of laboratories in gaining both cognitive and technological control over the world outside their walls. Scholars have demonstrated, for example, how the late-Victorian Cavendish Laboratory helped buttress the integrity of the British Empire through the calibration of electrical standards used in telegraphy, or how the Parisian linguistics laboratory of Third Empire France, and its graphic representations of spoken language, granted the metropolis leverage over the provinces and their patois. Historically and historiographically, the laboratory and its products provide a particularly rich site in which to observe the complex interactions of science and culture as well as their role in the consolidation of nations and empires.[5]

The laboratories at DRTE participated in this broader tradition. The Establishment had originally been formed through the merging of two laboratories—the Radio Physics Laboratory (RPL), created in 1947 to deal with problems of radio propagation in high Northern latitudes and particularly in the strategically crucial Canadian North; and the Electronics Laboratory (EL), created in 1950 to provide technical support for the RPL and to carry out "anticipatory research" in advanced electronics. DRTE itself formed part of a much broader research effort, spurred by the post-war enthusiasm for science and coordinated by the Canadian Defence Research Board, to provide 'a unique contribution' to the research activities of the West by focusing on fields in which Canada possessed special talent or facilities, and especially in those fields best-suited to its geographic position.[6] Alongside the broader projects of the Defence Research Board—climatic investigations, topographical analyses, entomological experiments—DRTE would try to establish reliable telecommunications to the Canadian North by exerting cognitive control over the ionosphere above it. In 1957 the RPL and EL were joined by the Communications Laboratory (CL), where the ionospheric physics of the Radio Physics Laboratory met the advanced technology of Electronics Lab. The satellite project that emerged from the Communications Laboratory in early 1959 was, at its most basic level, an attempt to extend the tradition of radio-physical investigations begun with RPL by drawing on

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[5] For the case of the Cavendish, see Simon Schaffer, "Late Victorian Metrology and Its Instrumentation: A Manufactory of Ohms," in *The Science Studies Reader*, ed. Mario Biagioli (New York: Routledge, 1999), 457-478; on the linguistics laboratory of Etienne Jules Marey, see Robert Brain, "Standards and Semiotics," in *Inscribing Science: Scientific Texts and the Materiality of Communication*, ed. Timothy Lenoir (Stanford: Stanford University Press, 1998), 249-284. Also, on the now classic case of Louis Pasteur, see Bruno Latour, *The Pasteurization of France* (Cambridge: Harvard University Press, 1988).

[6] Donald J. Goodspeed, *A History of the Defence Research Board of Canada* (Ottawa: Queen's Printer. 1958), 25.

the growing electronic expertise and material culture of the Electronics Lab.

The Visual Cultures of the Radio Physics Laboratory

The S-27 project built on a long tradition of ionospheric research at the Radio Physics Laboratory stretching back to the Second World War. RPL's roots lay in a small research unit assembled by the Royal Canadian Navy in 1941 to investigate radio disruptions in the North Atlantic and the peculiar ionospheric conditions believed to cause them. These disruptions—often severe, sometimes total blackouts—wreaked havoc on wartime radio and direction-finding circuits in the North Atlantic, thwarting Allied telecommunications and facilitating the work of German U-boat commanders. Housed in Section 6 of the Navy's Operational Intelligence Centre (OIC/6), a division concerned with code-breaking, counterintelligence and anti-submarine warfare, the unit was placed under the leadership of Frank T. Davies, a meteorologist and Welsh émigré who had been introduced to ionospheric research through geophysics and meteorology.[7] Davies had served on a number of scientific expeditions to the Arctic and Antarctic in the late 1920s and throughout the 1930s, he carried out meteorological and geophysical measurements, particularly of the magnetic, auroral and ionospheric phenomena that fascinated him. Following a posting as director of the Carnegie Geophysical Observatory in Huancayo, Peru, in the late 1930s, he joined British Intelligence and was later seconded to OIC/6 from the National Research Council in the early years of the Second World War to oversee its ionospheric propagation programme.

Davies' interests in geophysical measurements and atmospheric observations would stay with him all his life. Long after his professional duties had turned administrative, careful meteorological notes on temperature, wind properties, and precipitation would find their way into his diaries. More importantly for our purposes, Davies interests would shape the culture of the Radio Physics Laboratory from the time of its creation in 1947.[8] Under Davies's direction, OIC/6 mounted the first systematic

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[7] Although meteorology is generally associated with the study of weather, it is actually a diverse field encompassing applied, dynamic and physical meteorology, aerology (the study of the free air not adjacent to the earth's surface) and aeronomy (which includes upper atmospheric physics and therefore ionospheric investigations).

[8] Davies's commitment to geophysical investigations as a means of improving communications after the war would perplex and sometimes enrage his military overseers, who came to see the postwar Radio Physics Laboratory as an academic luxury—an organization engaged in basic research, and therefore not a defence unit at all, but rather a purely scientific establishment. See biographical notes on Frank T. Davies, held at the

Canadian studies of the ionosphere. From tiny ionospheric field stations scattered across the country in the late 1940s, partially processed data made its way through virtually every communications medium in postwar Canada—telephone, telegraph, teletype, air mail, regular mail, confidential messenger and radio—to Davies's group in Ottawa.[9] Using these data to improve wartime radio communications was by no means unique. What characterized the approach of Davies's group vis-à-vis British and American researchers (against which they defined themselves) was its emphasis on the *physical* and the causal, rather than the *statistical* and the correlative aspects of radio propagation.[10] In a mantra that would guide the work of RPL for the next two decades, Davies argued that the path to reliable radio required a scientific excursion through the geophysics of high northern latitudes.

Of all the field-station data used by Davies and his colleagues—absorption measurements, oblique incidence measurements, radio reception conditions, auroral observations—the most important by far were the measurements derived from ionograms. Since the mid-1920s, when Merle Tuve and Gregory Breit had begun using oscilloscopes and radar equipment to investigate ionospheric phenomena (before their respective entries into atomic physics), the notion of an 'experiment' in ionospheric research had quickly become associated with the production of a visual record. The instrument that produced that record was known as an ionosonde—essentially a modified radar set that shared extensively in the material culture of its sibling.[11] Through a series of timing, gating and

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Communications Research Centre, Ottawa (formerly the Defence Research Telecommunications Establishment).

[9] National Archives of Canada, Department of National Defence Record Group 24 (hereafter NAC, RG 24) vol. 4058, file NSS 1078-13-8, vol. 1, "Notes on Discussion of Ionospheric Measurement and Radio Transmission Work of Laboratories at London, Sydney, and Washington, 30 December 1942 to 9 January 1943," 12 January 1943, 3.

[10] This way of approaching radio problems—through physical and dynamical investigations rather than statistical correlations—would gain momentum after the war. As evidence that this approach characterized the work of Davies's group, Norwegian Defence Research Establishment (NRDE) adopted RPL's more 'scientific' approach to the problems of northern radio communications after a visit to RPL in 1955. See Olav Wicken, "Space Science and Technology in the Cold War: The Ionosphere, the Military, and Politics in Norway," *History and Technology* 13 (1997): 207-229.

[11] On the early history of ionospheric research and the role of visual images, see C. Stewart Gillmor, "Threshold to Space: Early Studies of the Ionosphere," in *Space Science Comes of Age: Perspectives in the History of the Space Sciences*, eds. Paul Hanle and Von del Chamberlain (Washington, D.C.: Smithsonian Institution Press, 1981), 101-114. In the late 1940s, ionosondes were often assembled from surplus military radar equipment. Some have argued vigorously for the ionosonde as the initial step towards operational radar. Oswald Villard has claimed that Merle Tuve's observation that reflections from

amplifier circuits, the ionosonde emitted a series of pulses of gradually increasing frequency. These pulses traveled into the upper atmosphere where, depending on the electron density they encountered, they might be reflected back to the ionosonde's receiver before being fed to a cathode ray oscilloscope. Through careful measurements made directly on the oscilloscope, researchers could manually construct height-versus-frequency (h'f) graphs of ionospheric propagation.[12] Building on wartime improvements in radar technology, post-war instruments sought to automate the tracing process, first by focusing the oscilloscope image on 35mm film while moving the film through a camera at constant speed; and later by adding two 'panoramic' displays, which automatically plotted the time delay (or virtual height) of the radio echoes against their frequency characteristics, thereby creating the same h'f curves as station technicians might, but without the difficulties and uncertainties of manual intervention.[13]

The resulting records, known as "panoramic ionograms," quickly became the preferred graphical tools in upper atmospheric physics and high-frequency communications. Like the bubble chamber image of 20th-century microphysics, or the indicator diagram of 19th century thermodynamics and engineering, the ionogram of the 1950s was iconic. Like so many scientific records, its appeal lay partly in its ability to render static the otherwise fleeting characteristics of nature, in the fact that it seemed to represent a "picture" of the ionosphere.[14] By automating the construction of height-versus-frequency curves, the panoramic ionogram effectively transformed the process of ionospheric research from one rooted in tracing—either manual or mechanical in the case of the early ionosondes—to one based on seemingly instantaneous photography. Its

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planes were interfering with phase-path measurements in 1929 prompted radar development; see Oswald G. Villard, "The Ionospheric Sounder and its Place in the History of Radio Science," *Radio Science* 11 (1976): 858. C. Steward Gillmor has similarly pointed out this significance of ionospheric research.

[12] The use of this system at Canadian ionospheric stations at the end of World War II is documented in the transcript of the Canadian Radio Wave Propagation Committee Conference. NAC, RG 24, vol. 3412, Canadian Radio Wave Propagation Committee Conference, 22-27 October 1945, 27.

[13] Indeed, T.R. Gilliland, who introduced the automatic ionosonde in this form, claimed to do so in order to save time and labour, as well as to capture the details of an often rapidly-changing ionosphere. T.R. Gilliland, "Note on a Multifrequency Automatic Recorder of Ionospheric Heights," *Bureau of Standards Journal of Research* 11 (1933): 561-566.

[14] This realist impulse in ionospheric research has been examined in Gillmor (note 11). For the case of 'sporadic E' ionization, see Kenneth Davies, "Ionospheric Radio Propagation," *National Bureau of Standards Monograph*, 80 (Washington, D.C.: National Bureau of Standards, 1965), 150.

ability to capture even the most fleeting characteristics of the ionosphere in a formalized graph allowed researchers to pore over them at length, analyzing, measuring, recording and incorporating its features into larger experimental results and theoretical conclusions.[15]

For all its broad appeal, the ionogram became central to the specific practical and political cultures of the post-war RPL, and of DRTE's ionospheric and radio research more generally. It first of all appealed to the two principal groups making up RPL, ionospheric physicists like Davies and communications engineers. Each group *read* a single ionogram in different ways. Upper atmospheric physicists read the graphs *backwards*, as it were, through magneto-ionic theory, thermodynamics, and cosmic ray physics to assemble views of ionospheric structure and dynamics. Radio engineers, on the other hand, read the images *forward*, through the laws of optics and through a series of propagation theorems that converted scaled quantities into maximum usable frequencies, optimal working frequencies and skip distances for communications circuits.[16] The dual nature of the records, their ability to simultaneously speak to the interests of ionospheric and radio physicists alike, made them central to RPL's mission of establishing reliable northern communications through investigations of Canada's peculiar northern geophysics.

But for RPL the ionogram was also the solution to problems in the place of experiment. Throughout the years immediately following World War II, the laboratory directed considerable resources against the troubling effects of the northern and rural environment that the ionospheric field stations occupied. For the laboratory, the rigours of the field raised troubling epistemic difficulties. Frank Davies repeatedly argued to his

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[15] For a fascinating account of the similar role of recordings in the history of linguistics, see Brain. Bruno Latour has pointed to the broader importance of measurement in relation to two dimensional images. In his essay "Drawing things together," he explains how the result of the merging of image and geometry is "that we can work on paper with rulers and numbers, and combinations of numbers and tables can be used which are still easier to handle than words or silhouettes. You cannot measure the sun, but you can measure a photograph of the sun with a ruler... This is what I call, for want of a better term, the second-degree advantage of inscriptions, or the surplus-value that is gained through their capitalization."; Bruno Latour, "Drawing Things Together." in *Representation in Scientific Practice*, eds. Michael Lynch and Steve Woolgar (Cambridge: MIT Press, 1990), 46-47.

[16] Some have suggested that the radio scientific roots of ionospheric research led to a phenomenological approach to ionospheric physics. See Davies, 153; S.A. Bowhill and E.R. Schmerling, "The Distribution of Electrons in the Ionosphere," in *Advances in Electronics and Electron Physics*, 15, ed. L. Marton (New York: Academic Press, 1961), 256-326; and Gillmor, 101-102.

superiors that the instruments of the field stations *could* produce good records, but required "constant skilled supervision."[17] Training had to be carried out on site, Davies lamented, "sometimes by men who have not had sufficient training themselves. Inaccuracy and serious errors in data have occurred because of this."[18] The itinerant nature of the northern workforce added to these difficulties. The panoramic ionosonde, which automated the production of ionograms, was meant to solve the problem of producing records reliably. But in many ways, it only displaced the problem of reliability. The graph captured more phenomena more reliably, but it made the field operators' job of *reading* the ionogram much harder. Furthermore, the accepted techniques for reading ionograms in the late 1940s and early 1950s, techniques developed by British and American researchers in the decades before the war and based on the much simpler ionograms from temperate latitudes, treated many of the characteristic phenomena on Canadian records as aberrations. The standards of ionographic interpretation in the late 1940s, when RPL began its work, did not know how to treat these records and others like them. In response, RPL launched a programme to develop its own authoritative rules for reading high-latitude ionograms, rules that would be adopted internationally in 1957 for the International Geophysical Year.[19] With the production and reading regimes intact, the ionogram could now represent the peculiar effects of the turbulent high-latitude ionosphere—the spread echoes, Z-modes, and polar spurs that distinguished the "Canadian ionosphere" from that of the U.S.A. or Britain—furnishing the visual evidence behind arguments for Canadian distinctiveness into the 1960s. Through the production and circulation of ionograms, the Laboratory's work of extending reliable communications to the Canadian North was materially, socially, and culturally structured by two dimensions: its total dependence on two-dimensional representations of peculiar ionospheric

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[17] NAC, RG 24, vol. 3414, file 468-3-3, Frank T. Davies, "Minutes of Canadian Radio Wave Propagation Committee, Ionospheric Propagation Sub-committee," 22 May 1944, 2.

[18] NAC, RG 24, vol. 83-84/167, file 7401-1710, Frank T. Davies, Memorandum to Vice-Director General, Defence Research Board, 16 July 1947, 1.

[19] The authors of the IGY manual would admit that the standard scaling techniques had proved "far from satisfactory for world-wide use." See "Manual on Ionosphere Vertical Soundings," *Annals of the IGY*, 3, part 1, eds. J. W. Wright, R. W. Knecht and K. Davies, (London: Pergamon Press, 1957), 111. The choice of these records was due partly to the geographical distribution of the laboratories (primarily American and European) that had developed the interpretation practices, and partly because in the particular simplicity of these records researchers hoped to more readily find a suggestion of the universal. See J.A. Ratcliffe, "The Formation of the Ionosphere: Ideas of the Early Years (1925-1955)," *Journal of Atmospheric and Terrestrial Physics* 36 (1974): 2167.

phenomena and on the network of distant field stations that provided them.

Through these transformations in the practical and material cultures of the Radio Physics Laboratory and its field stations, ionograms had by the late 1950s become central to the politics, culture and practices of DRTE, and to the Establishment's claims about Canadian identity and geophysical particularity. DRTE researchers had put enormous efforts into turning the ionogram into an incredibly reliable and authoritative medium for representing the ionosphere above Canada. For all their utility and ubiquity in the late 1950s, however, ionograms possessed one crucial limitation: they could only furnish direct information on the so-called 'bottomside ionosphere,' the portion of the ionosphere lying roughly between 100 and 500 km above the earth.[20] Ironically, the same characteristics of radio propagation that made the ionogram possible denied researchers any direct knowledge about the region that lay beyond—the so-called "topside ionosphere". The purpose of the satellite project proposed in 1957 by the Communications Laboratory (formed from a nucleus of RPL researchers) was to extend the production of ionograms, along with the familiar and reliable scientific practices that surrounded them, to the investigation of this 'topside ionosphere'.[21]

The ionogram was not incidental here—it was central. For the ionospheric physicists and communications engineers at DRTE, the S-27 project was the culmination of an experimental tradition that stretched back almost two decades. In a proposal to their superiors at the Defence Research Board, CL researchers argued that a satellite orbiting at 1000 km and 80° inclination to the geographic equator could create an iconographic symmetry in ionospheric research, allowing the ionosphere to be

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[20] The ground-based ionogram will only render a comprehensive picture for an ionosphere of monotonically increasing electron density. This is because each pulse from the ionosonde propagates through the atmosphere until it encounters a region of the ionosphere with electron density: $N = \pi m f^2 / e^2$. Here, the radiation would be completely reflected, and the range to the reflecting region could be obtained by measuring the time delay between emitted pulse and received echo. Beyond a 'critical f', corresponding to the maximum electron density of the ionosphere, radio waves continued out into space. Any features of the ionosphere lying beyond this region, technically known as the F2 peak, would not be captured by the ionogram. In fact, through its own limitations, the ionogram actually helped define the 'bottomside' ionosphere, whose limits actually varied according to geophysical conditions and their diurnal and seasonal variations. On the history of the ionospheric layers, see Gillmor, 102, 105-106.

[21] This was intended, in part, to avoid the difficulties of data use like those described by John Krige in his discussion of the European Meteorological Satellite. See John Krige, "Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite," *Technology and Culture*, 41 (2000): 27-50, on pages 28-29.

inscribed, for the first time ever, from the ground out to the borders of space through the cognitively dependable ionogram.[22] The nagging question of how to produce these crucial images reliably, in the hostile environment at the borders of space rather than the isolated spaces of the North, would fall to the Electronics Laboratory of DRTE.

The Material Cultures of the Electronics Laboratory

For two decades after the Second World War, the Radio Physics Laboratory had been deeply concerned with the reliable production, circulation and interpretation of ionograms. Those concerns had always centred on the large and unwieldy ground-based ionosondes used at the field stations. Although the satellite project marked a shift in the material culture of ionographic production from vacuum tube-powered, ground-based sounders to solid-state driven, space-based ionosondes, the concerns over generating ionograms in inhospitable environments crossed that divide. But how did an organization like the Electronics Laboratory, completely inexperienced in satellite construction, approach the problem of producing the ionogram reliably from space?

Technologies are not automatically reliable entities; and scientific instruments are no exception. Despite years of scholarship that treated the knowledge-producing capacity of instruments as relatively unproblematic, over the past two decades we have seen again and again how social and cultural contexts help transform instruments into "transparent" tools of science.[23] That same literature has repeatedly suggested how vast areas of post-war research—particle physics, solid-state computing, medical

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[22] On the orbital considerations for S-27, see NAC, John Chapman Fonds (MG 31 J 143), vol. 9, John Chapman, "Proposal for a Sweep Frequency Ionospheric Sounder for Installation in a Satellite," 1958, 2.

[23] Simon Schaffer has examined at length this 'transparency' in relation to Newton's prisms, and his experiments on the nature of light; see Simon Schaffer, "Glass Works: Newton's Prisms and the Uses of Experiment," in *The Uses of Experiment: Studies in the Natural Sciences*, eds. David Gooding, Trevor Pinch, and Simon Schaffer (Cambridge: Cambridge University Press, 1989), 67-104; Bruno Latour has used the term "black-boxing" to describe the process by which instruments are made unproblematic. See Bruno Latour, "Give Me a Laboratory and I will Raise the World," in *Science Observed: New Perspectives on the Social Study of Science*, eds. Karin D. Knorr-Cetina and Michael Mulkay (Beverly Hills, CA: Sage Publications, 1983), 141-170. Also Steven Shapin and Simon Schaffer have studied the often intense work of negotiation and coordination involved in establishing the air-pump as a reliable tool of natural philosophy; see *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985).

electronics—were made possible by the machinery of war.[24] And space science, with its roots in weapons engineering and military organization, benefitted disproportionately from these connections.[25] Modified ballistic missiles carried nuclear warheads and scientific probes alike into the upper atmosphere and beyond. Technologies designed for the nuclear battlefield—radiation shields, telemetry transmitters, Geiger counters, miniature electronics—entered into weapons systems and space experiments alike. The inexperience of the members of DRTE in space electronics, this literature suggests, is ultimately less important than their deep immersion in the material and epistemic dimensions of a military culture of reliability, underwriting vast spheres of cold-war technology.

If we approach the S-27 project as a novelty, as the launching point in a long line of satellite projects, we risk missing the way it was rooted in profound concerns over the reliability of technologies during the Cold War. In situating it within these concerns, however, we need to avoid appealing to a monolithic and undifferentiated military culture of reliability. The Cold War demanded that electronic technologies be ever-reliable. In doing so, it changed the way that electronics was conceived, developed and even understood. But rather than creating immediate consensus, the Cold War spawned competing visions of what caused unreliability in electronics and how it might be eliminated. The S-27 satellite was one historically specific answer to the problems of reliable electronics in the late 1950s. We want to avoid treating the satellite as a

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[24] Peter Galison, for example, has demonstrated the connections between the material culture of war and the material culture of microphysics; see P. Galison, *Image and Logic: A Material Culture of Modern Physics* (Chicago: Chicago University Press, 1997), especially chapters 4 and 6. For the adoption of radar technology in medical imaging, see E. Yoxen, "Seeing with Sound: A Study of the Development of Medical Images," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, eds. T. Pinch and W. Bijker (Cambridge: MIT Press, 1987), 281-303.

[25] See B. Hevly, *Basic Research within a Military Context: The Naval Research Laboratory and the Foundations of Extreme Ultraviolet and X-Ray Astronomy, 1923-1960* (Ph.D. Dissertation, Johns Hopkins University, 1987). For the specific case of post-war rocket research in the U.S., see D. DeVorkin, *Science with a Vengeance: How the Military Created the US Space Sciences After World War II* (New York: Springer-Verlag, 1992). The links between weapons laboratories and space science has been carefully laid out by Clayton Koppes in his study of the Jet Propulsion Laboratory. See C. Koppes, *JPL and the American Space Program: A History of the Jet Propulsion Laboratory* (New Haven: Yale University Press, 1982). Walter McDougall explains the common grounding of both enterprises in the military-industrial complex; See *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 157-236. And Olav Wicken has studied the military connection in Norwegian space science during the Cold War; see Wicken, "Space Science."

generic technology and instead see it as a particular and contingent product of the engineering culture of the Electronics Laboratory—one out of a number of historically specific alternatives to the pressing concerns about the trustworthiness of electronics.

Throughout the 1950s, the question of how to construct reliable electronic equipment had enormous relevance beyond the satellite project, beyond the Electronics Lab, even beyond DRTE. It lay at the centre of a "reliability crisis" that afflicted both Western and Soviet defence establishments early in the decade.[26] Report after report argued that the growing electronic infrastructures of the Cold War—the increasingly complex systems of radar and atomic weapons, gunlaying and guided missiles, surveillance and communications—were massively unreliable. One report from 1950, for example, suggested that a full two-thirds of Western military electronic equipment might be malfunctioning.[27] At the core of the crisis lay practical and epistemological concerns: What were the practices and concepts through which engineers might create reliability? How could the reliability of electronic equipment best be known?

Two main answers to these questions emerged over the course of the 1950s. The early view of the reliability crisis was dominated by what we might call a "monist" perspective, which viewed reliability as a problem of individual electronic parts. It had entered the U.S. ballistic missile programme mainly through émigré German rocket engineers, and was adopted at the highest levels of the Canadian Armed Services in the early 1950s. It carried analytical force—at its simplest level, the reliability of a system is given by the product of the individual part reliabilities; and it rested on a quasi-ontological foundation that saw individual electronic devices as atomic constituents, "an item which cannot be disassembled without destroying its identity".[28] Combined with the obvious materiality of electronic failure (the fact that failures manifested themselves physically in electronic parts), the monists argued convincingly for one causal explanation of the reliability crisis, one view of where the reliable functioning of electronic equipment resided. Why did a piece of electronic equipment stop working? Simply put, it stopped working because one or several of its fundamental constituents had ceased to function properly.

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[26] NAC, RG 24, vol. 2484, file 801-E447-1, part 1, "A Proposed RCAF Policy and Organization for System Reliability" (24 June 1963).

[27] Keith Henney, ed., *Reliability Factors for Ground Electronic Equipment* (New York: McGraw-Hill, 1956), 1-1.

[28] Morris Halio, "Improving Electronic Reliability," *IRE Transactions on Military Electronics* MIL-5 (1961): 12.

By the mid-1950s, however, that view of reliability had begun to come under sustained attack from what we might call a dualist programme, which instead focused on *both* electronic parts *and* the larger circuits in which parts operated. The dualist criticisms emerged most forcefully in the late 1950s, in the wake of Sputnik, from isolated sections of the Department of National Defence, and particularly from the Air Material Command (AMC) of the Royal Canadian Air Force. Its most vocal champion within the Canadian military was an engineer and leading member of the Air Material Command named Chester Soucy. For Soucy, one of the major errors of the monist view was that it focused too heavily on a category of electronic failure known as "catastrophic failures"—incidents in which equipment failed to operate altogether rather than simply malfunctioning.[29] The focus on catastrophic failures “due to their dramatic obviousness” had caused military planners and even engineers to neglect the “less dramatic but more prevalent problem of malfunctions due to gradual degradation of parts.”[30] The greater problem for reliability, Soucy maintained, was with the design of *circuits*, the larger electronic environments in which individual parts experienced their catastrophic failures. By Soucy’s lights, the monist programme might possibly ensure the reliability of relatively simple military electronic equipment; but it simply could not do so for the dizzyingly complex electronic systems demanded by the RCAF.[31] Guidance systems and proximity fuses for missiles, fire control systems for supersonic aircraft, even instrumentation for satellites—these systems, Soucy argued, demanded a level of reliability surpassing anything the monists could offer. Granted, catastrophic failures *were* materially localized in individual parts; but in areas like radar and missiles, unreliability had to be conceived more broadly, and had to consider failures of design.

The Electronics Laboratory was created six months before the outbreak of the Korean War. Its mission was to conduct what officials called ‘anticipatory research’ into military electronics—investigations into advanced communications, electronic countermeasures, missile guidance, digital computing and eventually space technology. Throughout the 1950s, the laboratory formed a crucial component of the monist programme. The EL’s Components Section was charged with ensuring

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[29] For a discussion of catastrophic failure versus degradation failure, see J. C. Cluley, *Electronic Equipment Reliability* (New York: John Wiley and Sons, 1974), 100-102.

[30] NAC, RG 24, accession, 1983-84/049, vol. 1664, file 1950-123-7, part 2, C. Soucy, “The ‘Project MATURE’ Concept of the Design and Production Requirements for Reliable and Maintainable Military Electronics Equipment,” presented to the Third Institute of Radio Engineers Convention, Toronto, Canada, 8 October 1958, 5.

[31] Soucy, fig. 2.

the robustness and performance of individual electronic parts and with advising the Armed Services and industry on their findings.[32] Through its provision of the Secretariat for the Electronic Components Research and Development Committee, the Components Section also tied DRTE into the most widespread reliability programme for electronic parts in Canada, and linked it to similar efforts in the U.K. and the U.S. with which the committee coordinated its activities.[33] By the closing years of the decade, however, the affinities of the Electronics Laboratory for the dualist programme had been instantiated in the organization and layout of the lab. In 1954, it added a second section alongside the Components Section and dedicated to electronic circuits, particularly those involving transistors. By 1957 the new section had grown to include several subdivisions—Transistor Measurements and Radio Frequency Receivers, Digital Techniques, and Advanced Circuit Research.[34] The foundational work that went on there was recognized in the new title given to the section: Basic Circuits.

Like the Components Section, Basic Circuits worked to combine extreme robustness with high performance. But it searched for this combination in collocations of electronic parts rather than in the individual parts themselves. Drawing materially on the robust parts that flowed from the Components group, the section struggled throughout the 1950s, during the height of the reliability crisis, to fashion robust circuits.[35] Its engineers developed their approach mainly through a number of projects undertaken for the Royal Canadian Air Force, including the Doppler radar for the CF-105 (the Avro Arrow). For nearly six years, the members of Basic Circuits worked on reconciling the functional requirements of radar with the robustness required for supersonic flight. It enlisted Simpson's team, with its connections to CAMESA and its involvement in the monist programme, to carefully screen individual components.[36] It called on members of Basic Circuits to transistorize the design. For over a year, guided by the reliability demands of Chester Soucy and the Air Material Command, a group of technicians and a design team led by engineer Colin Franklin struggled to combine electronic stability and temperature compensation in the components with the necessary radiation

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[32] Goodspeed, 203.

[33] NAC, RG 41, vol. 110, file 3-23, part 1, "Defence Research Board: Electronic Component Development Committee, Terms of Reference," 12 February 1954.

[34] NAC, RG 24, accession 89-90/205, P.M. Thompson, "The Graphic Nomenclature of Transistors," (n.d.) Defence Research Board, Canada, EL Memorandum No. 5059-50B.

[35] Goodspeed, 203.

[36] Communications Researh Centre, Frank Davies Papers, Letter from John N. Barry to Frank T. Davies, "Doppler Navigator Development," (16 October 1973): 5.

characteristics for the radar. Understanding the dire consequences of malfunctions in navigation systems during supersonic flight, Franklin and his team sought to reconcile radar fidelity with electronic reliability.[37] With the cancellation of the aircraft in 1959, the Doppler project ended and the Doppler Section was transformed, with much of its staff and expertise intact, into the Satellite Section to begin work on S-27.

The dualist approach, developed for the exigencies of guided missiles and supersonic flight, now dominated the design, construction, and testing of the S-27 satellite. As Andrew Molozzi, one of the principal engineers for the project, asserted: "The approach taken placed particular emphasis on the integrated design of the circuitry, that is, components in the circuit rather than on individual component parts alone."[38] Robust electronic parts were still crucial to the project, and members of the Satellite Section sought to ensure their reliability by incorporating only 'proven' parts into the satellite instrumentation. But alongside these attempts to identify and create robust electronic parts was an attempt to isolate optimal configurations, 'preferred' circuits. All circuits for S-27 were tested over a temperature range of -50C to +75C even though thermal design studies and tests had shown that actual payload temperatures would only vary between -7C and +45C. The same circuits were tested over simultaneous voltage fluctuations of between 25 percent and 50 percent, despite the fact that the same studies and tests had shown that voltages would be held to ±5 percent.[39] Test soundings from the ground determined whether the robust circuits that emerged from the process could adequately meet the ionographic demands of the mission. And the rigorous process of testing and examination then continued outward to larger and larger assemblies, eventually involving the entire payload.

An interesting irony emerged from this process and from the instrument it produced. The concepts and practices that DRTE technicians and engineers employed to ensure the reliability of military electronic equipment, the tenets of the dualist philosophy of reliability that they had been developing under the intense pressures of the Cold War, received their greatest justification, not through the reliable deployment of missiles or aircraft, but from the production of scientific records. In the days and weeks following the successful launch of S-27, letters of congratulations

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[37] Barry, 2-3.

[38] A.R. Molozzi, "Instrumentation of the Ionospheric Sounder Contained in the Satellite 1962 Beta Alpha (Alouette)," *Space Research IV: Proceedings of the Fourth International Space Science Symposium, Warsaw* (1964), 427.

[39] Molozzi, 417; NAC, RG 24, acc. 83-84/167, box 7315, file 0204-01, vol. 2, John Mar, "Notes on Fifth Meeting of Topside Sounder Working Group at CRPL 12 October 1960: Appendix C."

poured into the office of Frank Davies, now DRTE's Chief Superintendent. Among those letters came one from the British physicist J.A. Ratcliffe, colleague and friend of Sir Edward Appleton and, next to him, the world's senior ionospheric specialist. From his office at the Radio Research Station of the British Directorate of Scientific and Industrial Research in Slough, Ratcliffe began:

> There is now no doubt at all that everybody here feels that you and your people have done a most wonderful piece of work in the making of this equipment. None of us has ever seen such good ionograms *even when taken from the ground.* It is quite amazing that results of this kind should have been produced, and even more amazing that they should have been produced by a group of workers who have never before put an experiment into a satellite. I should imagine that this experiment of yours is one of the most complicated and ambitious that has yet been made.[40]

Given the inexperience of DRTE in satellite construction, the achievement surprised Ratcliffe and others. It should surprise us a little less. Everywhere around the technicians and engineers of the S-27 project was a culture of reliability. S-27 was, from its beginnings, immersed in a formidable cultural apparatus, elaborated in the 1950s, and dedicated to the construction of reliable electronic instruments. Parts screening, testing-to-failure, derating, advanced circuit design, centrifuge tests, vacuum and thermal chambers—these were the conceptual and material expressions of a specific philosophy of reliability championed in military circles in the late 1950s and early 1960s, embodied in the organization and activities of DRTE, and directed towards (among other projects) the construction of S-27. The entire physical and cultural infrastructure that ensured the reliable functioning of military technology, that transformed potentially untrustworthy electronic entities into dependable military electronics, was marshalled towards the construction of a reliable scientific instrument and received its ultimate validation from the ionograms it helped produce.

Conclusion

So we end where we began—with ionograms and satellites. But we have benefited from this detour through laboratory cultures. For the scientists, engineers and technicians at DRTE in the late 1950s, the S-27 project was as much a culmination of scientific and technological traditions as it was a starting point for future satellite communications. For the atmospheric physicists and radio engineers of RPL, S-27 was rooted in a

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[40] NAC, RG 24, accession 1983-84/167, box 7316, file 0204-01, part 6, letter from J.A. Ratcliffe to F.T. Davies, 9 October 1962. Original emphasis.

research programme stretching back to the wartime North Atlantic, to the shortwave radio blackouts that plagued high-northern latitudes in the early Cold War, and to the peculiar scientific images that promised to overcome them. For the engineers and technicians of the Electronics Laboratory, the satellite had potentially very different linkages. Tied to Doppler navigation systems, high-speed switching circuits and supersonic aircraft, the satellite participated in a tradition of cold-war electrical engineering obsessed with how to make technologies trustworthy. The same beliefs and practices designed to hold military technology in a state of constant readiness, to render it dependable in the impending and punishing environment of nuclear war, helped safeguard the reliable production of ionograms in the harsh conditions of space.

My suggestion that we focus on S-27 rather than Alouette, on what the satellite was in the late 1950s and early 1960s rather than what it would become in future decades, might be open to misinterpretation. So let me be clear about what I have *not* been arguing. I am not arguing that the satellite did not represent some sort of rupture in ionospheric research for the members of RPL, or that the satellite designers did not have communications satellites in mind when developing S-27. Clearly they did. Nor am I arguing for a view of that would turn the series of satellites engineered by DRTE into a kind of technological Potemkin Village, with each instrument standing in isolation rather than in series. What I have argued for is a view of the S-27 project that puts aside one of the most constant and central preoccupations in the history of Canadian science and technology: its obsession with innovations, discoveries and inventions, its constant search for success stories.

Some nations need scant justification as foci for scholarship; they command their own legitimation. Cold war science and engineering too have their icons. ICBMs, nuclear weapons, subatomic research, solid-state electronics—these are the material and cognitive foundations for innumerable aspects of that conflict and the world it helped shape.[41] But as I suggested at the outset of this paper, when taken seriously and on their own terms, the laboratories of DRTE suggest that the history of Canadian science and technology can also command our attention. In details that may seem mundane—the reading of ionograms, the design of electronic circuits—the laboratories of DRTE argue forcefully for how science and technology were used again and again to carve out authority

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[41] Albert Moyer has pointed to the dominance in the historiography of modern physics of what he terms "Los Alamos-based histories," studies that take the wartime work of nuclear physicists as both the culmination of prewar developments and the birth of postwar patterns. See Albert Moyer, "History of Physics," *Osiris* 1 (1985): 163-182.

and autonomy under the totalizing pressures of the Cold War. Ionospheric research and electrical engineering alike simultaneously reinforced and threatened the emerging geopolitical order. They show us that if the principal means of prosecuting the Cold War were technological and scientific, then the means of fighting its totalizing tendencies were scientific and technological as well. Exploring these struggles, waged across the postwar globe, moves us away from the conceit that the only stories to be told are those centred, directly or by proxy, on Washington or Moscow. What is more, it sheds new light on the perennial question of what is Canadian about Canadian science and technology.[42] It does so, not by using that question to guide a search for essences, but by making the question itself the subject of historical investigation.[43] What did the members of the *laboratory* see as distinctive about their research? How did those views engage, subvert, or transform understandings of the nation? Or, put differently, how can we see the idea of the nation take shape in the workings of a laboratory? In seeking answers to those questions, we can speak to much wider concerns in the history of science and technology. Like Proust witnessing the entire town of Combray spring from his teacup, we can begin to see the nation inside the laboratory. There *is* metaphysics in our histories, if we only care to look.

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[42] For a classic study of this question, see Trevor Levere, "What is Canadian about Science in Canadian History?" in *Science, Technology, and Canadian History*, eds. R. A. Jarrell and N. R. Ball (Waterloo: Wilfrid Laurier University Press, 1980), 14-22.

[43] Gabrielle Hecht has urged just such an approach in her study of nuclear power in post-war France. See *The Radiance of France: Nuclear Power and National Identity After World War II* (Cambridge: MIT Press, 1998). On Canada, see Suzanne Zeller's masterful work *Inventing Canada: Early Victorian Science and the Idea of a Transcontinental Nation* (Toronto: University of Toronto Press, 1987).