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Flows to bytes: Digitising naval space

Introduction

Whether testing climate projections, chemical compounds, economic theories, or engineering solutions, computer models are ubiquitous in simulating dynamic environments.[1] Yet, despite computers in the twenty-first century proving remarkably adept at translating model-based simulation practices to digital signals, computation and the physical environments they simulate are far from being in simple alignment with one another. The use of models in experimental simulation practices has a long and epistemologically diverse history[2] spanning post-war explorations in computation to contemporary practices. How digital technologies are embedded in dynamic and complex systems, such as a ship in relation to water, is, however, anything but clear.

In September 1959, this inconclusiveness was captured in black and white when the superintendent of the British Navy's Admiralty Experiment Works (AEW), A. J. Vosper, outlined the "facilities" and "ship-model instrumentation" at the agency's disposal. His report was presented at the annual conference of test tank superintendents—the Symposium on Towing Tank Facilities, Instrumentation and Measuring Technique.[3] It was thus prepared for and presented to a specialised audience with a keen interest in the experimental apparatus of the British Navy's first research establishment. This interest was particularly well placed, since this apparatus's entanglements with digital computation were being allowed for the first time to be publicly, if only partially, displayed. When the Manoeuvring Tank installation was commenced in 1953, Vosper's report declared: "[. . .]it was decided to install a digital computer as part of the initial equipment with the primary function of experiment data reduction." The report expanded upon the computation's benefits:

> Its use not only saves a considerable amount of effort on normal routine calculations [. . .] but also can be brought to bear on calculations which *could not previously have been attempted* [because], if carried by computing staff, [they would] take such a long time that the chance of an error would increase prohibitively.[4]

Vosper's tone throughout the report manifests that his account (like most communications coming out of military establishments) aspired to be straightforwardly descriptive. Still, perhaps unintentionally, his language in the report reveals an ambivalence, as he wavers, framing the role of computers at the AEW in incommensurable terms. On the one hand, he portrays electronic computers as mere accelerators of established computational practices, enabling calculations previously envisioned but never attempted, on the other, as critical infrastructure for an altogether new type of experiment. His account, otherwise direct and unambiguous, becomes strikingly blurry when assessing digital computation's impact on the AEW's operations.

This peculiar oscillation, between computation's obvious usefulness in calculation and its capacity to support prediction, as part of an experimental infrastructure, begs the question: What was the impact of digital computers on environments of experimental simulation, such as in post-war ships' movement through water, and how might this spatialise contemporary understandings of computation's relation to water? Reaching for answers, I suggest, may entail telling a history of early computing from a watery site, the Manoeuvring Tank of the Admiralty Experiment Works. Centring on water can lead to potent, if peripheral, sites of computing history where the minutiae of digital computers' transition, from calculators to simulators, becomes most pronounced. But more importantly, in a historiographic reorientation of simulation histories away from atmospheric—whether air defence, air travel, or air conditioning—and towards liquid domains, water's materiality is not incidental.[5] That the specificities of matter were central to simulation practices will, of course, not be surprising to the reader of simulation histories. After all, already in the nineteenth century, long before the term "computer" signified a machine, the transition towards simulation relied on expressing material behaviour mathematically.[6] Rather than resolving dynamics solely in mathematical formulations, however, in the case of the AEW, water's flow—its twists, swirls, ripples, and vortices, as well as the ensuing roll, pitch, heave, and acceleration of bodies immersed in it—were observed through physical simulations in three-dimensional space. In particular, water furnished these spaces with a positional system that constituted a "liquid intelligence" in many ways irreconcilable with the dry, grounded linearity of the Cartesian grid that transcribed the experiments into computable information. In fact, what watery sites like the Manoeuvring Tank suggest, I argue, is that the translation of in-water simulated behaviour into flat computable data was mediated by a series of documentation techniques whose agency was redefined by the introduction of digital computers; it was compound photographic, and other practices, which arbitrated the transcription of aqueous space, and its dynamics, into bytes.[7]

Bringing to the fore the media landscape in which the computerisation of simulation practices occurred, at the time of the Manoeuvring Tank experiments, this essay recontextualises these "dead" media objects to articulate ways in which they shaped the subsequent emergence of computer simulations.[8] Through such water-related media objects, this essay redirects attention away from long-lived undercurrents of architectural discourse, such as form or style, and towards how a multivalent array of media, including water and buildings, relate to one another. Rather than trust that interrogating a building's plan, materiality, or precedents is essential to writing architectural history, this essay asks how architecture can operate as part of a larger technological apparatus.[9] It contends that the scope of architectural history can extend beyond the building to other related arts, artefacts and media, such as those so central to the AEW. Specifically, centring on water-contingent techniques or technologies, the essay traces the shifts, evolutions and transformations in the AEW's documentation methods to argue that they made simulation "thinkable" by at once facilitating and limiting its development. And crucially, this essay engages in an excavation of simulation documentation media without wishing to make an argument for, or against, computer-induced historical discontinuities in scientific practice. Rather, through the AEW's built environments of aqueous simulation, it demonstrates a dialectical relationship between new technologies like digital computation and dynamic experimental practices.

Computational (dis)continuities

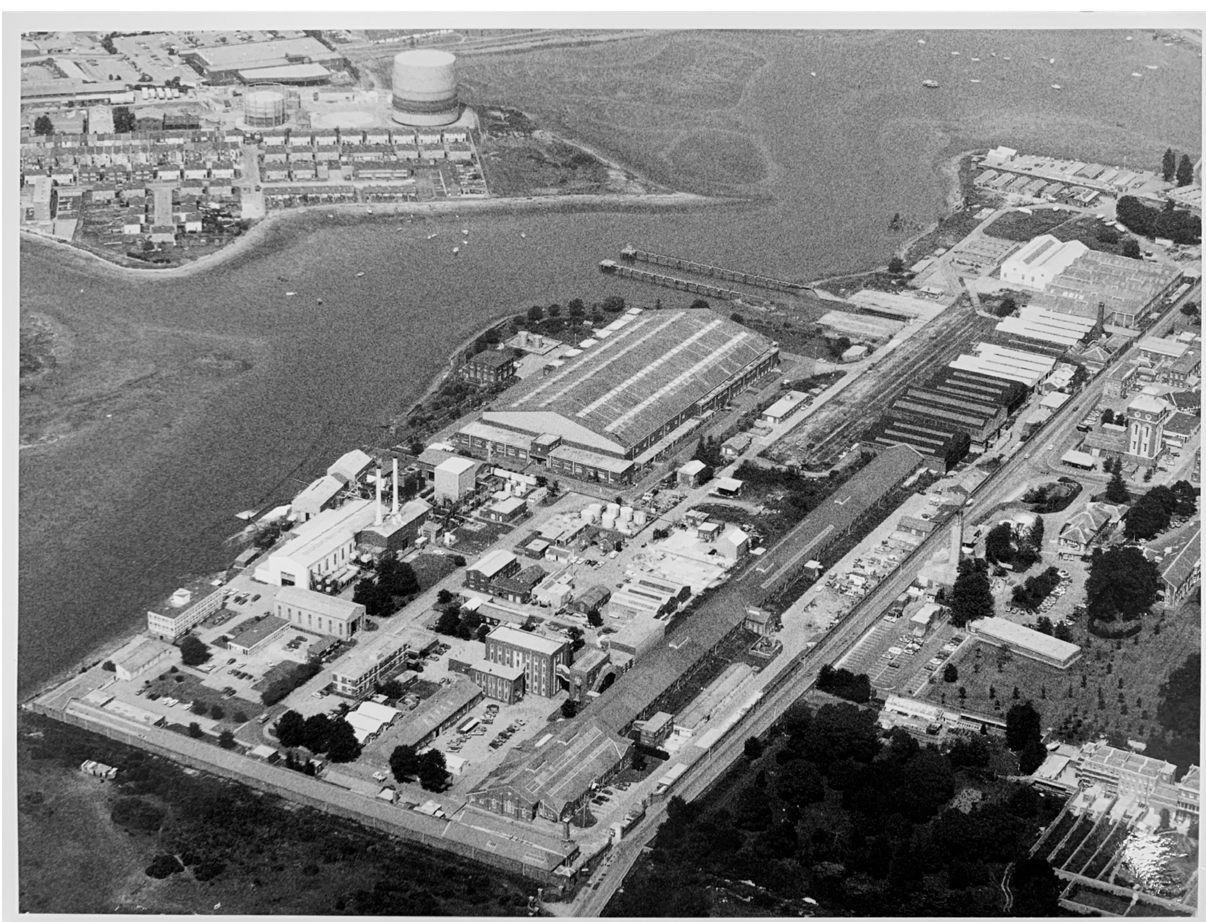
Vosper's ambivalence between the calculation and prediction capacities of computers, recounted above, tracks a historiographical schism, a vignette of which is offered by the literature on digital computation's imprint on mid-twentieth-century microphysics. Scholars, most notably Peter Galison, positioned digital computation at the centre of scientific developments.[10] Whether operating as *a substitute for human labour* or as *a substitute for nature*, the computer, Galison's story goes, undergirded the very possibility of certain scientific activities. As a replacement for labour, it displaced the scientist in mid-twentieth-century microphysics. Operating either as a standalone tool or as part of a "system [produced through] the thorough integration of 'scanning girl,' physicist, and electronic computer," digital computation performed functions previously conducted manually while confining human intervention in data extraction to preparatory work.[11] Adopted for its speed and accuracy across the "logic" and "image" traditions in microphysics, the digital computer, so Galison claimed, catalysed the 1960s reorganisation of computational methods and the ensuing merging of the two traditions. "Bit by bit," Galison evocatively writes, "the two cultures came together."[12] By the end of this process, the digital computer had drastically altered the landscape of high-energy physics research. Digital computers went beyond standing in for tools, they effectively stood in for nature itself. Case in point is the Monte Carlo, a mid-century computational method employing approximation via random sampling to simulate the outcome of physical experiments deemed either too dangerous to test or too complex to calculate. If born out of the material and mathematical realities of nuclear research, the Monte Carlo stood between experiment and theory, heralding nothing short of "a new mode of producing scientific knowledge."[13]

The vector of early digital computers driving paradigmatic change has also been drawn in the inverse direction.[14] Proceeding with suspicion towards accounts of discontinuity, historians like Jon Agar have argued that the computational methods employed by microphysicists and X-ray crystallographers remained constant. Any noticeable shift in computing practices was quantitative, not qualitative. Rather than the promise of new epistemic frontiers, what prompted microphysicists to adopt digital computation was the possibility of conducting *familiar* operations faster and more accurately. Monte Carlo did not introduce new modalities of scientific inquiry, so this story goes, as "Monte Carlo-style methods" predated digital computers and can be traced back to techniques of manual calculation.[15] That is to say, its digital operation was a direct analogue of familiar processes, only faster and translated into code. An Agar-fashioned view of this history, then, not only rejects the idea that digital computation ushered in new modes of scientific knowledge-production, but also asserts that electronic computers were only introduced "in settings where there *already existed* material and theoretical computational practices and technologies."[16]

Situating itself at the nexus of these compelling, if competing, accounts of electronic computation's impact on science, this essay seeks to articulate a framework for thinking through the operations of digital computers in dynamic simulation environments, where water, architecture, and documentation media form a continuous apparatus. It proceeds by maintaining that assigning primacy to either new technologies or existing practices can obscure what is argued to be a dialectic relationship between the two—a cyclical process of redefining each other's role, which allowed new experimental practices, like digital simulation, to emerge out of environments with pre-electronic traditions of physical simulation.

The AEW was precisely such an environment. Its nineteenth-century engineering inquiries positioned themselves in a similarly ambiguous territory—between theory and experiment—by modelling vessels and seas alike. Established in the aftermath of the catastrophic foundering of HMS *Captain* in 1870 as a recourse to the knowledge vacuum produced by naval architecture's transition from wood to iron, and from air to steam, the AEW's experimentation programme introduced an era of sustained hydrodynamic simulations in controlled environments.[17] The AEW's inaugural simulation facility, built in Torquay in 1871, comprised a

Fig. 1 Anonymous (ca. 1989). Aerial view of the Gunboat Yard site of the Manoeuvring Tank [Photograph, Science and Innovation Park Library, Wroughton]



rail carriage configuration moving six-foot-long wax models through water and recording, by means of a self-registering dynamometer, the experienced resistance. The apparatus also consisted of an architecture enclosing a linear test tank measuring two hundred and fifty by twenty feet and producing physically and materially what may anachronistically be called a space of naval simulation. The architectural articulation of this space reverberated to the new premises of the AEW, in the Gunboat Yard at Haslar, Portsmouth, where a facility replacing the Torquay basin was constructed in 1886 and a second, longer and more capacious tank, was completed in 1930.

The Manoeuvring Tank was erected on this site in 1959. Like its predecessors in Torquay and at Haslar, it produced a controlled, interiorised space, albeit this time for a type of inquiry newly emerging in the aftermath of World War II naval warfare.[18] Specifically, it was designed to accommodate physical simulations of vessels' seaworthiness, steering, and manoeuvring, to replicate those undertaken in the 1950s on the nearby non-tidal waterway of the Horsea Lake. An architectural response to newfangled experimental inquiries, the Manoeuvring Tank configured a waterscape that resembled little the linear waterways of its predecessors. It comprised a gargantuan steel roof housing a four-hundred-foot-long by two-hundred-foot-wide basin which was divided in two sections designed to emulate two different oceanic conditions.

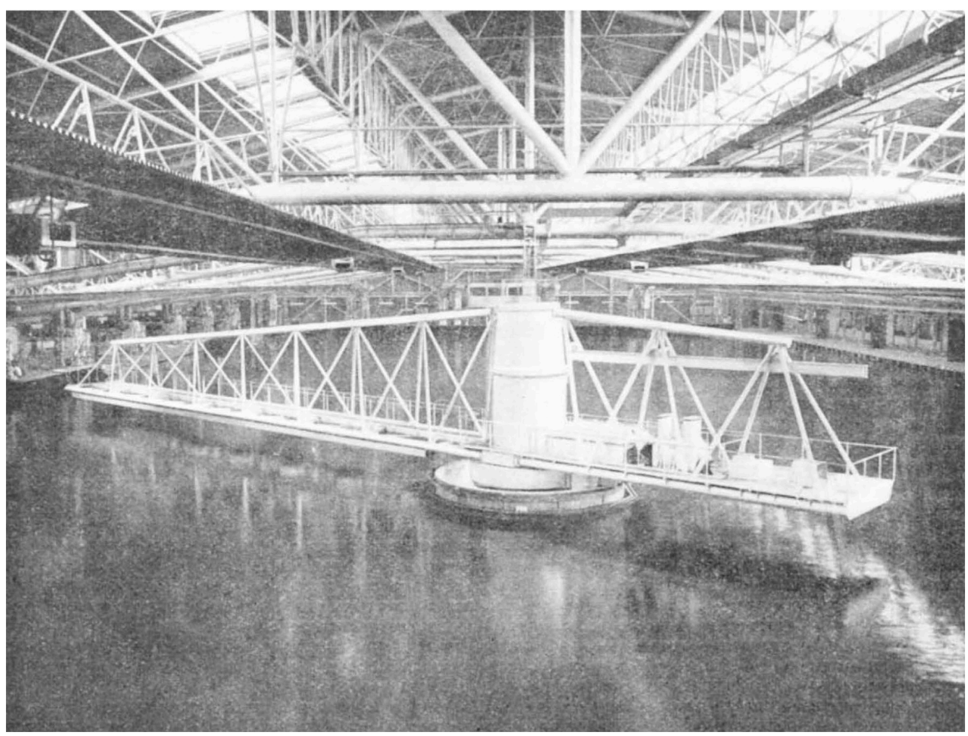


Fig. 2 Anonymous (1962). Plan of the experimental configuration of the Manoeuvring Tank [Drawing, Nature Publishing Group]

The was devoted to a mechanically rotating arm, which propelled models during manoeuvring tests while recording the resistance they experienced and the wave patterns they produced. The second section featured two sets of wavemakers and a stepped "beach" suppressing unsolicited or recoiling waves. It thereby articulated a contained, defined, and stable water space which, when animated by waves forming along two axes, could generate indoors the complex wave forms required for seaworthiness trials, and allow for an intramural simulation of conditions at sea.[19] As the intricacy of this artificial waterscape suggests, this

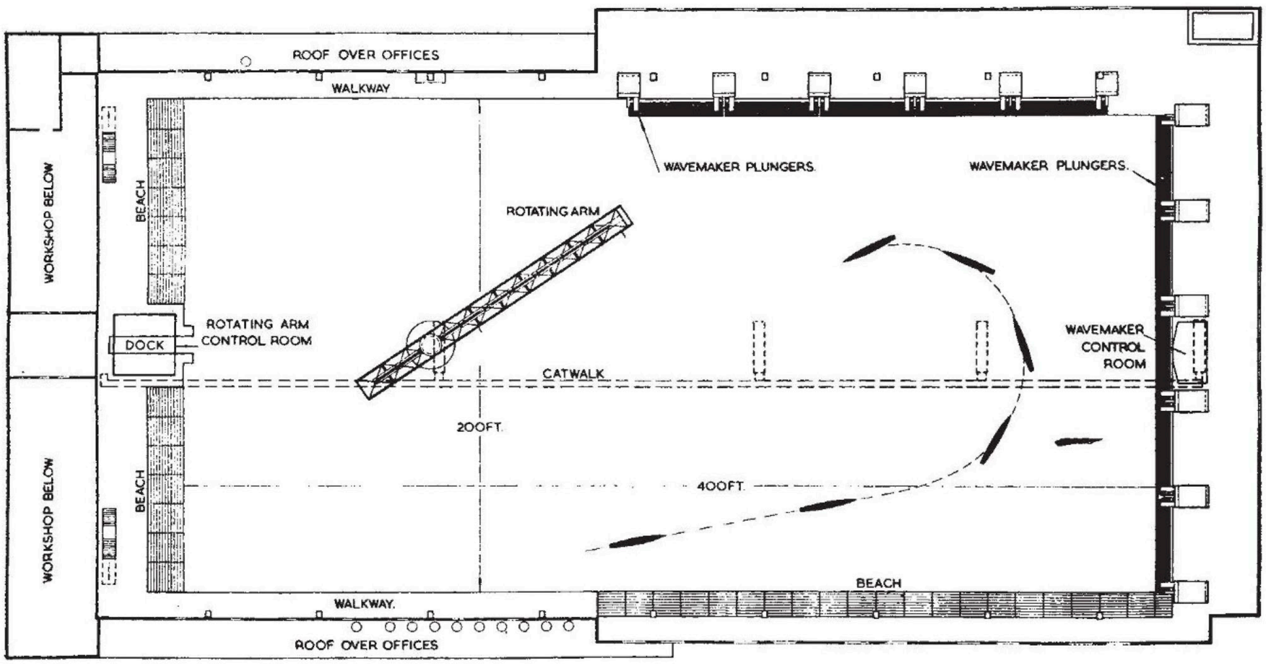


Fig. 3 Anonymous (1962). The water space of simulation in the Manoeuvring Tank with the rotating arm in the foreground [Photograph, Nature Publishing Group]

architecture did not merely interiorise unaltered pre-existing experimental practices. Rather, by inscribing the latter in a controlled architectural space, it reformulated the parameters of the inquiry in ways that exceeded the AEW's computational means, effectively necessitating additional computing resources. As Vosper made clear:

> When the Manoeuvring Tank installation was commenced in 1953, it was foreseen that the analysis of records from the rotating arm and seaworthiness basin would be a prodigious task which would have placed an onerous burden on the relatively small staff and also would have resulted in unacceptably long delays between experiments.[20]

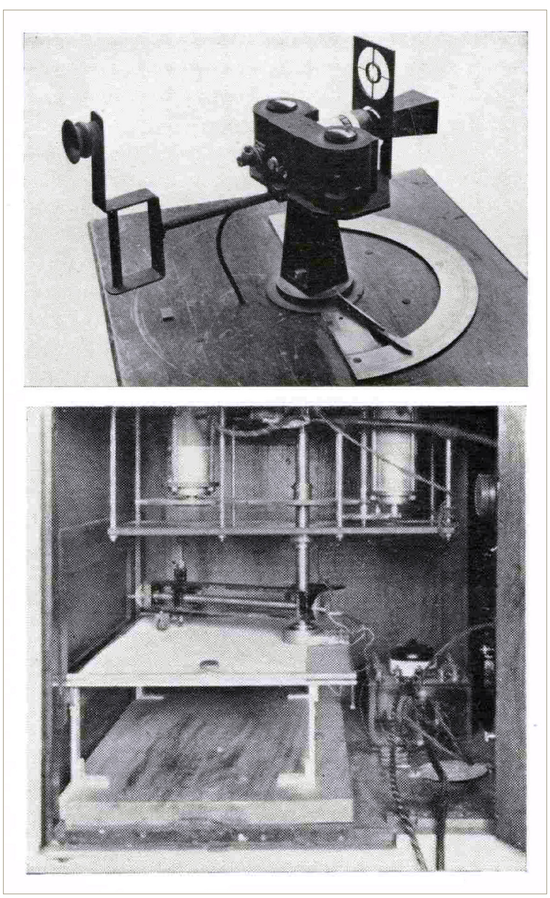
In other words, digital computation was introduced as a recourse to this unattainable "burden" of analysis. It was introduced in tandem with architecture, warranted by the new articulation of architecture's interface with water, that an indoors, non-linear, artificially animated seascape was produced. Although physical simulation—and the architectural configuration of simulation spaces—had been central to the AEW's experimental practices from its very inception, the Manoeuvring Tank recodified experimental simulation parameters, ushering in a new era of electronic computation whose capacities and limitations—whether in replacing human labour or serving as a substitute for entire simulation environments—would come to the fore.

Recording aqueous space

In his refashioning of Monte Carlo's computational dependence, Agar gestures towards digital computation's impact on representational practices. "The practices of computation were already in place," he writes, "only the final stage—representation of the object—was transferred to a new medium."[21] If the introduction of electronic computers did not reconfigure scientific experiments by instituting computation, but only occurred where manual computing methods were already an established practice, computers were nevertheless implied to have transformed graphical methods. Indeed, through the representation practices' friction with digital computation, I suggest, it became possible for computers to assume roles beyond performing pre-existing computational procedures: through a dialectic relationship between computational and representational techniques, computer simulations became thinkable. Thus, to trace how the AEW's techniques of simulating ship behaviour in architecturally modelled environments were transcribed to the digital space of computer simulations, we may turn to the graphical tools and methods through which the experimental records were produced.

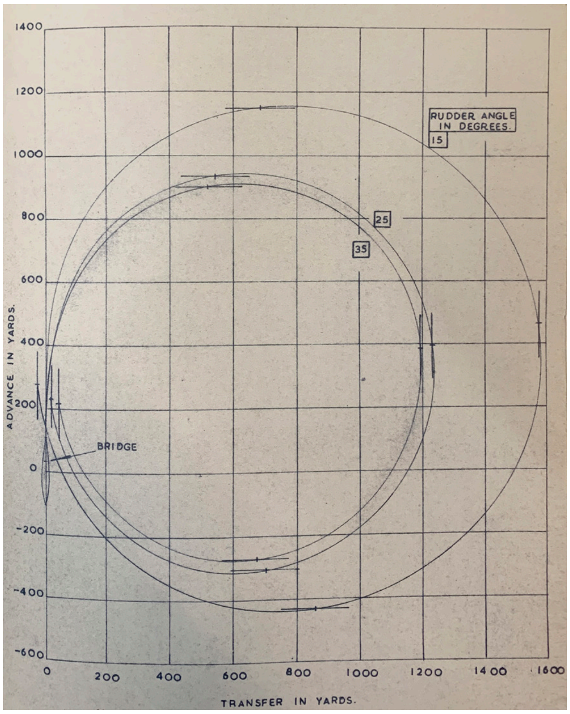
The codification of physical simulation results as information, through graphical means, had been part of the AEW's experimental procedures since its nineteenth-century origins.[22] Already in its inaugural facility, the experimental apparatus included a dynamometer recording the resistance experienced by models on a rotating drum.[23] If in the 1870s documenting trials meant assigning numerical values to phenomena like hydrodynamic friction through graphical means, after World War II, this practice included the position of models in space, with turning trials being the primary field of application. In 1950, for example, during the full-scale manoeuvring tests of HMCS *Magnificent*, the ship's paths at sea were documented by two "autographic bearing records" and subsequently transferred on a two-dimensional graph.[24] The latter represented the nautical space of the trials by virtue of curved lines on a grid, which rendered the local coordinates of the ship continually recuperable. This practice was echoed in model turning trials conducted—in the absence of a manoeuvring tank—on Horsea Lake. The graphs reproduced in the 1951 report of the HMS *Eagle* tests, for example, captured the model's path, turning, and lateral movement spatially.[25]

Fig. 4 Admiralty Experiment Works (1960). Automatic bearing recorders used by the Admiralty Experiment Works [Photograph, Nationaal Archief]



Whereas graphical practices captured physical simulations by representing a ship's course numerically, photography was called upon to overcome this abstraction. At its simplest, its application included photographic documentation of natural growths on a ship's hull.[26] But beyond producing records of static conditions, photography with high-speed cameras was employed, beginning in the 1930s, to document the movement of models, ships, or mechanical parts under trial. High-speed photography was, of course, not a new technology in the 1930s, and neither was its application to moving subjects. Eadweard Muybridge's canonical motion pictures and Étienne-Jules Marey's famous chronophotographic movement-capture in composite images had established the practice nearly half a century earlier. Although an old technique, chronophotography was nevertheless particularly well positioned to meet the 1930s demands of naval research, as studies of mechanical parts proliferated rapidly under the impetus to improve propulsion and thrust systems.

The widespread adoption of chronophotography by the AEW was facilitated by the 1920s development of the stroboscope. A lighting technology for high-speed photography, it was devised by Harold Eugene Edgerton at MIT in the mid-1920s to



make cyclically moving objects like motor parts appear stationary when captured on a photographic surface. Edgerton's method relied on matching the frequency of the strobe's flashes to the speed of a part's rotation and capturing it on film. As Vosper's report indicates, this type of high-speed photography became central to the AEW's propeller experiments conducted in cavitation tunnels during and after World War II. In his words, "an ultra-high speed camera, working up to a rate of 200,000 exposures per second [was] acquired [. . .] for this purpose" and used in tandem with a "portable wheeled console [. . .] permit[ing] fine control [. . .] of the stroboscopic lighting."[27] This assembly allowed the AEW staff to produce still photographic records of both the rotating model propellers and the circulation patterns of air and bubbles, effectively enabling the study of propulsion systems' hydrodynamic behaviour.[28]

Yet, scaled propellers were not the only models whose trials were recorded by a camera. Turning trials with models might have been numerically transcribed in graph form, as seen in the tracking of the *Magnificent*, but their manoeuvring paths on the surface of the artificial Horsea Lake were also documented photographically by a spatial apparatus. This consisted, as recounted in a 1948 inventory of facilities and equipment, of "a tower approximately 6 feet square and permitting a camera height of 23 feet" so as to allow overhead views.[29] The photographs produced and developed on site emulated

Fig. 5 Admiralty Experiment Works (1950). Graph recording a ship's path and bearing during turning trials at sea [Drawing, National Archives]

Fig. 6 Admiralty Experiment Works (undated). Photographic recording of model in Horsea Lake steering trial [Photograph, Imperial War Museum]

aerial views—rendered popular by aviation—all the while seeking to insert such views in a quantifiable plane of reference. To that effect, the tower's position was aligned with a white post located at the mid-length between two concrete blocks. Four such blocks were installed in total, raised above water level to define a rectangular sector of the lake within which trials were conducted. With all its reference points "accurately surveyed," the experimental infrastructure around the photographic tower pertained not to the experiments themselves but to their documentation; the apparatus was tasked with aligning photographic records of turning simulations with the physical space of Horsea Lake. That is to say, upon its introduction to the AEW, digital computation entered a landscape of graphic documentation techniques that mobilised penned ink or photography to inscribe movement through aqueous spaces into an analogue informational system, comprising concrete blocks in lakes and grids on paper, creating waterscapes of computing.

Waterscapes of computing

In the early 2000s, digitally simulated environments fused "image" with "logic," all the while blurring any distinction between physical and mathematical modelling.[30] Yet the watery sites of the AEW suggest that this blurring was already underway in the 1950s. "Propeller photography," "digital computation," and "recording by photographic methods," intertwined in Vosper's report, were also entangled in practice. The AEW's experimental practices were not merely housed by architecture but rather articulated an interface between architecture and water. Indeed, the 1959 facility codified the mediation of photographic (or composite) documentation techniques architecturally by consolidating their operation into a photographic laboratory,[31] all the while producing an aqueous space of simulation which made the acquisition of a digital computer imperative.

The machine acquired in response was a British-manufactured and Dutch-designed Stantec Zebra.[32] The Zebra was a mainframe digital computer selected, Vosper reported, because of its speed, "modest price," and simplicity of programming.[33] Being simple and fast, the Zebra was put to the task of performing calculations that were familiar, if sometimes too onerous to be attempted through manual or mechanical means.[34] Fittingly, water permeated the Zebra's operational terminology, with its speed being predicated on a mechanical technique termed "underwater programming." The implied submersion was, of course, not physical but informational insofar as it referred to minimising drum access, not a literal plunge.[35] A technique specific to Zebra machines, this informational submersion amounted to operating in bursts of autonomy by incorporating and modifying instructions (typically retrieved from the drum at every step) into data registers. That is to say, the Zebra was designed to function in conditions of communication scarcity, which, albeit artificially produced, emulated naval realities particularly acute in submarine domains. Even if strictly metaphorical, the Zebra's "underwater" operation highlights that water's materiality did not merely host the experiments whose records were analysed digitally but also posed very material limitations to the information system. As will be shown below, this attentiveness to water's affordances was inscribed on AEW documentation practices that negotiated the nexus between water, architecture, and information; it permeated the techniques through which a digitally simulated aqueous space became thinkable.

By the 1960s, AEW reports register a shift in terminology. Documents pertaining to computation practices had begun to adopt a language of *simulation* with references to "calculation," for example, giving way to "mathematical simulation."[36] Nomenclature shifts notwithstanding, little had changed in terms of what was being computed. Resolving manually the complex integrodifferential equations of motion (on which "mathematical simulations" relied) might have been unattainable at the rate required, but the equations themselves remained familiar mathematical formulations—by no means novel epistemic objects. What this new discourse did introduce, however, was an emphasis on the link between *simulation* and *information*. In the language of the 1962 *Porpoise* report:

> It cannot be emphasised too strongly that very little *information* for the *simulation* of H.M. S/M PROPOISE [*sic*] is available. [. . .] While this technique is ideally suited to this type of problem, it is impossible to ascribe quantitative accuracy to the results if accurate hydrodynamic *data* are not available for use in the equations of motion. *Experiments and full scale* [*sic*] *trials must be designed* to produce more of the coefficients for the simulation necessary for these studies.[37]

Computers might have indeed merely accelerated the computational practices already present in experimental environments like the AEW. But in doing so, they catalysed a process of translating simulations, using physical models, into quantifiable information. And they did so by virtue of the need for "accurate data," a process mediated by the AEW's documentation apparatus, as Vosper reported: "in the past, a number of trials have been carried out in which ship motions have been recorded in amplitude form on photographic film or with pen and ink recorders."[38] Here too, speed and the availability of (human) resources limited the efficiency of these practices. But this could be overcome through "automatic analysis." The automatic analysis of "pen and ink" records relied on "digital recording" techniques, which necessitated the use of either digitisers connected at the back of pen-recorders or an electronic analogue-to-digital converter—both tools that allowed experiment results to be captured in the form of punched tape. Such equipment was complex, costly, and prone to breaking down. Still, Vosper conceded that this form of digital recording was particularly valuable. And his reasoning had a computational bottom line: this practice permitted results to be entered "directly into the digital computer for analysis."[39]

Much like the datafication of experimental recordings, digital means also facilitated the "automatic analysis of film records."[40] This process, too, was contingent upon digital computation. Firstly, the practice itself was developed for seaworthiness tests conducted in the Manoeuvring Tank. These were precisely the kind of experiments enabled by this new architecture, the complexity of which had dictated the acquisition of a digital computer. Secondly, the self-propelled models tested in the Manoeuvring Tank, detached from any mechanical arm or railway carriage, could not accommodate recording apparatuses without inadvertently changing the parameters of their buoyancy. Therefore, trial data had to be acquired from a distance. "Passing the results ashore," as Vosper put it, was achieved through an Admiralty-developed ten-channel film recorder capturing the models' "roll, pitch, heave, acceleration, shaft revolutions, course and wave height."[41] These were "automatically converted [. . .] into *digital information*" by a second piece of specially developed equipment: an automatic analyser.[42] Beyond being applied alongside photographic recording, the newly introduced digital technologies reorganised the AEW's processes and instituted new practices of documentation. While digital computation was employed in an experimental setting where both computational and photographic practices pre-existed, it metabolised previous practices resulting in new, composite techniques and experimental infrastructures—including the architecture of the Manoeuvring Tank—aligned with the possibility of digital information.

The AEW's composite photographic practice of documenting turning trials in the Manoeuvring Tank encapsulates a dialectic relationship of cyclical redefinition in which the technique of photographic recording originally developed for manoeuvrability tests on Horsea Lake was adapted to align with the input requirements of digital computers, enabling the controlled intramural naval space of the tank to be understood as digitisable. The recording configuration consisted of a camera capturing:

> The path of the model during the run up and during the turn [. . .] by a multiple exposure on a single plate. The single camera used look[ed] down on the turning area so that the resulting circle show[ed] the position [of the model] at various points.[43]

Singular lights were mounted on the bow and the stern of the model. Placed at pre-defined heights, they allowed the model's position to be registered on a horizontal plane, even after the model's vertical position relative to water (sinkage) and roll along the lateral axis (trim) took effect. Once the model's movement was recorded chronophotographically, the two lights allowed the reduction of its position to two points on this plane, which was itself represented graphically in the form of a "specially constructed [perspectival] grid."[44] As with the language of simulation, the practice of retouching photographs was not novel to the AEW. As a 1950 inventory documents, besides Leica cameras and Watson microfilm viewers, tools such as "aerograph brush[es]" were part of the photographic studio equipment well before the Manoeuvring Tank was constructed.[45] But if editing photographs in post-production had been well established, following the introduction of (non-human) computers at the AEW, it was put to new use—inscribing experimental results into digital information. By virtue of overlaying a

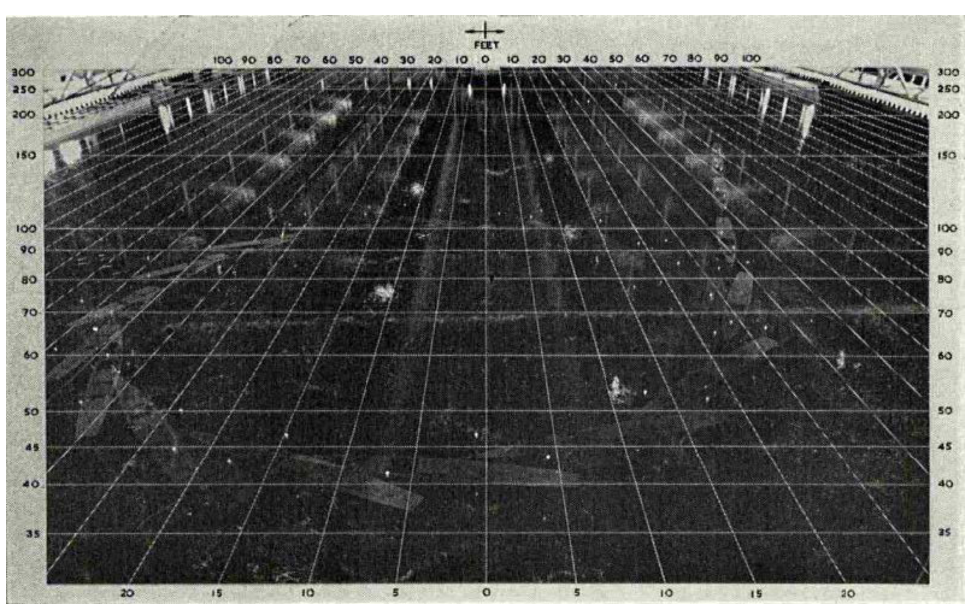


Fig. 7 Admiralty Experiment Works (ca. 1960). Chronophotographic recording of model in Manoeuvring Tank steering trial [Photograph, Nationaal Archief]

two-dimensional grid on multiple-exposure photographs, this composite technique allowed analysing the perspective distortion and unfixed datum of the water space. It enabled translation of the lights' positions into two-dimensional Cartesian coordinates, from which the values of relevant experimental parameters (tactical diameter, transfer, advance, and drift angle) could be extracted. In mediating between a positional system inflected by water and a reference plane defined by the architecture, it transcribed models' movements in space into data, codifiable as bytes.

While decades away from model trials being conducted in digitally simulated environments, such composite techniques, at the water's interface with architecture, made the possibility of tests in a digitally parametricised space conceivable. Digital practices of automatic recording, analyses of film records and the chronophotographic method of documenting turning trials were informed by digital computation. Shaped by its incorporation into the AEW's practices, they were developed in step with the new architectural infrastructure that produced the imperative for electronic computation and, in turn, these techniques produced the conditions of possibility for a new mode of scientific experimentation. They allowed a different role of the electronic computer to become thinkable. They made the conceiving of digital simulation possible.

Conclusions

That simulations have come to define the terms in which most complex systems are modelled and studied is a veritable truism. The lack of consensus on the epistemological status of digital simulation models has hindered neither their adoption nor their diversification.[46] Occupying the hazy space between the empirical and the theoretical, they produce results by "re-producing" phenomena and use an endlessly varying combination of theoretical models, empirical data, and "semi-empirical" heuristic principles derived from observation.[47] With questions on the significance of "theory-model-data" to experimental purity and control persisting, watery sites like the AEW Manoeuvring Tank suggest that asking *how* such environments came to be can lead to understanding the unstable interface of water and architecture, in concert with documentation techniques tasked to stabilise water, by transcribing its aleatory dynamics into digital information. In other words, whereas translating movement through spaces of experimentation into numerical quantities via graphical means predated digital computation, in the aftermath of computation's adoption, the relationship between physical and digital space became increasingly mediated by composite photographic practices. But while digital computation catalysed the development of the AEW's composite photographic documentation practices, these practices allowed for the role of digital computers to be redefined.

Tracing the story of digital computation at the AEW, then, complicates the historiographically consolidated assessment of pre-1960s computers as machines built merely for the procedural calculation of numerical data. It illustrates that the 1970s operationalisation of the image through computer graphics has an analogue prehistory, with image recordings "made to compute and perform actions, to take up and simulate space."[48] And crucially, it suggests that crediting computers with paradigmatic change in experimental environments or, inversely, relegating them solely to facilitators of epistemically familiar processes obscures the intertwinement of digital computation and recording practices that took place in intramural aqueous modelled environments: such stories of digital computation fail to recognise the agency of water and architecture acquired through their interface.

Within the history of the 1950s Admiralty Experiment Works, digital computation was one more inscription technology entering a multifarious landscape of media. It relied on having operational value—computation's survival was contingent on its ability to integrate with the agency's multiple media recordings of experimental processes. Electronic computers were incorporated into a broader technological apparatus comprising an aqueous site of simulation with its physical space defined, produced, and stabilised by architecture, and transcribed into data through composite documentation techniques. That is to say, the introduction of digital computation at the AEW offers a tale of simulation, computation, and documentation enmeshed in a process of dialectic redefinition. But it also reorients concerns with architectural specificity—be it through genealogies of form, technique, or matter—towards an attentiveness to buildings' relational operation within a landscape of technologies: it tells a story of architecture, computers, and water as a layered system of media.

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NOTES

1. Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (MIT Press, 2010); Johannes Lenhard, Günter Küppers, and Terry Shinn, "Computer Simulation: Practice, Epistemology, and Social Dynamics," in *Simulation: Pragmatic Construction of Reality*, edited by Johannes Lenhard, Günter Küppers, and Terry Shinn (Springer Netherlands, 2006); Eric B. Winsberg, *Science in the Age of Computer Simulation* (University of Chicago Press, 2010); Mary S. Morgan and Margaret Morrison, *Models as Mediators: Perspectives on Natural and Social Science*, Ideas in Context, 52 (Cambridge University Press, 1999).

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3. A. J. Vosper, "A Review of Facilities and Ship-Model Instrumentation at the Admiralty Experiment Works, Haslar," Symposium on Towing Tank Facilities, Instrumentation and Measuring Technique, Zagreb, Brodarski Institute, Paper No. 3 (1959).

4. Vosper, "A Review of Facilities;" my emphasis.

5. That is not to suggest that the primacy attributed by historians of computation to all things air is an unjustified bias. On the contrary, in a 1950s historical inversion, even naval research itself was shaped by the fast advancing and much better funded domain of aeronautical engineering. For examples of post-war entanglements of digital computing with air see Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America*, Inside Technology (MIT Press, 1996); Clark A. Miller and Paul N. Edwards (eds), *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, Politics, Science, and the Environment (MIT Press, 2001); Yuriko Furuhata, *Climatic Media: Transpacific Experiments in Atmospheric Control*, Elements (Duke University Press, 2022).

6. In Naomi Oreskes's words, "if one could calculate the required properties of materials in a scale model, . . . then there was actually no need to build the model itself." Naomi Oreskes, "From Scaling to Simulation: Changing Meanings and Ambitions of Models in Geology," in *Science Without Laws: Model Systems, Cases, Exemplary Narratives*, edited by Angela N. H. Creager, M. Norton Wise, and Elizabeth Lubneck (Duke University Press, 2007), 113.

7. Oreskes sees the propelling of this mathematisation occurring in two phases: first, by the Victorian interest in geological time, and second, by the Cold War preoccupation with nuclear waste. Oreskes, "From Scaling to Simulation," 113.

8. For a thorough account of dead media objects in computing histories see Jacob Gaboury, *Image Objects: An Archaeology of Computer Graphics* (MIT Press, 2021).

9. For in-depth discussions of complex mediatic operations' pertinence to architecture, architectural discourse, and architectural history see John Harwood, *The Interface: IBM and the Transformation of Corporate Design, 1945–1976* (University of Minnesota Press, 2011); Reinhold Martin, *The Organizational Complex: Architecture, Media, and Corporate Space* (MIT Press, 2003). For architecture's friction with a language of "flows" developed for conceptualising computational processes see Matthew Allen, *Flowcharting: From Abstractionism to Algorithmics in Art and Architecture* (gta Verlag, 2023).

10. Peter Galison, *Image and Logic: A Material Culture of Microphysics* (University of Chicago Press, 1997).

11. Galison, *Image and Logic*, 371–385.

12. Galison, *Image and Logic*, 532.

13. Galison, *Image and Logic*, 119.

14. Jon Agar, "What Difference Did Computers Make?," *Social Studies of Science* 36, no. 6 (2006): 869–907.

15. In fact, Agar argues that whether digital computers were the optimal solution for performing Monte Carlo calculations remained an open question. Alternatives, including manual and mechanical methods, were tried and compared. Allocating resources to this exploration would be unjustifiable, he points out, if it had been certain that Monte Carlo methods were only feasible through the use of stored-program computers. Agar, "What Difference Did Computers Make?"

16. Agar, "What Difference Did Computers Make?," 872.

17. For more on William Froude and the early days of the Admiralty Experiment Works see David K. Brown, *The Way of a Ship in the Midst of the Sea: The Life and Work of William Froude* (Periscope Publishing Ltd., 2006); Larrie D. Ferreiro, *Bridging the Seas: The Rise of Naval Architecture in the Industrial Age, 1800–2000* (MIT Press, 2020). For more on earlier model ship trials under the objective of improving the sailing qualities of warships by testing hulls' resistance, stability, buoyancy, trim, and leeward drift see Simon Schaffer, "Fish and Ships: Models in the Age of Reason," in *Models: The Third Dimension of Science*, edited by Soraya de Chadarevian and Nick Hopwood (Stanford University Press, 2004); Bernhard Siegert, "Waterlines: Striated and Smooth Spaces as Techniques of Ship Design," in *Cultural Techniques: Grids, Filters, Doors, and Other Articulations of the Real*, Meaning Systems, First edition (Fordham University Press, 2015); David McGee, "From Craftsmanship to Draftsmanship: Naval Architecture and the Three Traditions of Early Modern Design," *Technology and Culture* 40, no. 2 (1999): 209–236.

18. "New Manœuvring Tank at Admiralty Experimental Works," *Nature* 193 (1962): 817–819.

19. Vosper, "A Review of Facilities."

20. Vosper, "A Review of Facilities," 49.

21. Agar, "What Difference Did Computers Make?," 872.

22. For more on "digitisation" or the codification of objects as digital information see Chris Wiggins and Matthew L. Jones, *How Data Happened: A History from the Age of Reason to the Age of Algorithms* (W. W. Norton & Company, 2023); Harry M. Collins, *Artificial Experts: Social Knowledge and Intelligent Machines* (MIT Press, 1990); Simon Schaffer, "Accurate Measurement Is an English Science," in *The Values of Precision*, edited by M. Norton Wise (Princeton University Press, 1995).

23. This arrangement deviated little from the established configuration of nineteenth-century self-registering instruments. For more on the AEW apparatus see Brown, *The Way of a Ship in the Midst of the Sea*.

24. "H.M.C.S. MAGNIFICENT Turning Trials," 26 January 1950, ADM 226/68, The National Archives, London.

25. "H.M.S. EAGLE Turning and Manoeuvring Trials," 21 December 1951, ADM 226/72/71, The National Archives, London.

26. "Inventory of Experiment Facilities and Equipment at Admiralty Experiment Works, Haslar," 1948, ADM 226/66, The National Archives, London.

27. Vosper, "A Review of Facilities," 43–49.

28. See, for example, "H.M. Submarine OTTER Propeller Photography Trial," June 1964, ADM 226/458, The National Archives, London.

29. "Inventory of Experiment Facilities and Equipment at Admiralty Experiment Works, Haslar," 361.

30. Chadarevian and Hopwood, "Dimensions of Modelling," 8.

31. The 1959 facility saw the consolidation of film-processing small dark rooms, previously incorporated within the vibration and electronics laboratories, into a photographic laboratory, constructed on site as a separate building. For photography in the new facility see Matthew Bristow, *The Admiralty Experiment Works Haslar, Gosport* (Historic England, 2016), 60.

32. Standard Telephones and Cables Limited, "Stantec Zebra: Electronic Digital Computer," 1957.

33. Vosper, "A Review of Facilities," 51.

34. Vosper, "A Review of Facilities," 49.

35. Willem Louis van der Poel, "The Logical Principles of Some Simple Computers" (PhD thesis, University of Amsterdam, 1956); Willem Louis van der Poel, "Micro-Programming and Trickology," in *Digitale Informationswandler/ Digital Information Processors/ Dispositifs Traitant Des Informations Numériques*, edited by Walter Hoffmann (Springer, 1962).

36. "Analogue Computer Investigations of Emergency Manoeuvres on H.M.S/M Porpoise," November 1962, ADM 226/793, The National Archives, London.

37. "Analogue Computer Investigations;" my emphasis.

38. Vosper, "A Review of Facilities," 53.

39. Vosper, "A Review of Facilities," 53–55.

40. Vosper, "A Review of Facilities," 55.

41. Vosper, "A Review of Facilities," 55–56.

42. The importance of this digitisation was such that the AEW underwent a process of deliberation on the means to achieve it. Before the development of the specialised equipment human labour was considered but was deemed too prone to error. Vosper, "A Review of Facilities," 55; my emphasis.

43. Vosper, "A Review of Facilities," 58.

44. Vosper, "A Review of Facilities," 58.

45. "Inventory of Experiment Facilities and Equipment at Admiralty Experiment Works, Haslar," 31 January 1950, ADM 226/68/3, The National Archives, London.

46. Matthew L. Jones, "Calculating Devices and Computers," in *A Companion to the History of Science*, Wiley Blackwell Companions to World History (Wiley-Blackwell, 2016), 476–477.

47. Paul N. Edwards, *A Vast Machine*.

48. Jacob Gaboury, *Image Objects*, 7.