Engineering Theories Within Carnapian Received View[*]

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Abstract

This paper extends the received view picture of natural science theories (specifically Carnap's version of it) to engineering theories. In the first part of the paper, drawing from the history of fluid mechanics, specifically the episodes where natural and engineering sciences diverge, this study identifies the distinct goals, concerns, and methodological approaches shaping the two enterprises. A natural science inquiry demands a theoretically mature framework that explains not just observational facts, but the empirical laws themselves, thereby saying more about the world than mere empirical generalizations can. Conversely, answering engineering questions requires developing tools and empirical generalizations—based on experiments—to account for and control a specific class of phenomena or devices, without necessarily needing an explanatory theoretical account for those very laws and tools. In the latter part I employ the covering law and dual-level conception of languages for reconstruction of the historical analysis to establish a structural demarcation criterion. It states that, while scientific theories unify theoretical and observational vocabularies through correspondence rules to maximize explanatory power, engineering models achieve practical utility by incorporating uninterpreted, extraneous observational vocabulary (O_{extra}). This reliance on O_{extra} grants engineering models an ad-hoc, stipulative logical strength at the direct expense of theoretical unity.

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1 Introduction

The received view of theories (RV) is largely concerned with natural science theories and to some extent with social, economic theories. But theories of engineering science are almost entirely missing from the purview of this picture. This might, perhaps, be explained by assuming that most logical positivists associated with RV took engineering theories to be *applied* natural science theories. Whatever the reasons for its absence, I will try to show that the resources of the RV picture are apt for developing an account of engineering theories.

Within the philosophy and history of technology scholarship, there is a substantial support for the thesis that knowledge of technology and that of natural science are quite distinct and that this difference somehow stems from their different epistemic objectives. While technology does produce knowledge in the process of production, use, repair and maintenance; it is never the primary objective. The primary objective remains practical utility of some kind. Houkes[1] provides the most detailed review of technological epistemology, noting that theoretical development in the field has been largely at a standstill since the 1990s. He, along with Hansson[2] and others, observes that historians of technology generally agree that technological knowledge possesses a form distinct from scientific knowledge. However, neither the precise nature of this technological knowledge nor the formal basis of its separation from science has been convincingly articulated. These two challenges constitute the central problems of the widely accepted "autonomy thesis." Houkes notes that, for the most part, this autonomy is tacitly assumed to follow simply from the distinct goals of the two enterprises—namely, "truth" versus "practical utility"—a view quite similar to Rogers[3]'s analysis. Yet, Hansson rightly points out that distinct goals do not automatically guarantee distinct epistemological structures; the formal explanatory accounts of these respective domains must stand on their own distinct footings. In this context, Vincenti's[4] seminal work is viewed as a major contribution to tech-

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[1] Wybo Houkes. "The Nature of Technological Knowledge". In: *Philosophy of Technology and Engineering Sciences.* Elsevier, 2009, pp. 309–350. DOI: `10.1016/B978-0-444-51667-1.50016-1`.

[2] Sven Ove Hansson. "Experiments Before Science. What Science Learned from Technological Experiments". In: *The Role of Technology in Science: Philosophical Perspectives.* Ed. by Sven Ove Hansson. Dordrecht: Springer Netherlands, 2015, pp. 81–110. DOI: `10.1007/978-94-017-9762-7_5`.

[3] G. F. C. Rogers. *The Nature of Engineering.* London: Macmillan Education UK, 1983. DOI: `10.1007/978-1-349-06683-4`.

[4] Walter Guido Vincenti. *What engineers know and how they know it: analytical studies from aeronautical history.* Johns Hopkins studies in the history of technology. Baltimore

nological epistemology. It also operates on the autonomy thesis and attempts to provide a formal account of engineering science as a unique branch of productive knowledge. Vencenti[5], leaves the discussion of how practical issues intervene in production of knowledge at "[p]ractice, as the word implies, is an activity—the major one in engineering. It uses and sometimes itself produces knowledge. It can also interact in various ways with experiment and theory, and this interaction can likewise produce knowledge. Knowledge, however, is not its primary goal."

In this article I will develop an account of how the practical concerns, primarily in the form of a need to account for a class of observational phenomena in absence of a theoretical framework, acts as the primary epistemic difference in natural and engineering sciences. I will argue that engineering models achieve practical utility by incorporating uninterpreted, extraneous observational vocabulary (O_{extra}). This reliance on O_{extra} grants engineering models an ad-hoc, stipulative logical strength at the direct expense of theoretical unity. In Section 2, I analyze the history of the split between hydraulics and hydro-dynamics into natural and engineering sciences and identify the distinct goals, concerns, and methodological approaches shaping the two enterprises. And in Section 3 I employ the covering law and dual-level conception of languages of the received view for a reconstruction of the historical analysis to establish a structural demarcation between engineering and natural sciences. In the concluding Section 4, I summarize the results and discuss its limits and general implications.

2 Hydraulics and Hydrodynamics Split

Michael Eckert explores the historical split of fluid dynamics into theoretical hydrodynamics and practical hydraulics by analyzing two issues at the heart of this divide: the efflux problem[6] and the turbulence problem[7]. Eckert notes that by "the 20th century the study of fluid motion fell into one of two classes: either the observed flow could be described in terms of hydrodynam-

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London: Johns Hopkins university press, 1993.

[5] Walter G. Vincenti. "The Experimental Assessment of Engineering Theory As a Tool for Design". In: *Techné: Research in Philosophy and Technology* 5.3 (2001), pp. 124–130. ISSN: 2691-5928. DOI: `10.5840/techne2001533`.

[6] Michael Eckert. "The efflux problem: how hydraulics became divorced from hydrodynamics". In: *Archive for History of Exact Sciences* 78.2 (Mar. 2024), pp. 127–152. ISSN: 0003-9519, 1432-0657. DOI: `10.1007/s00407-023-00320-2`.

[7] Michael Eckert. *The Turbulence Problem: A Persistent Riddle in Historical Perspective.* SpringerBriefs in History of Science and Technology. Cham: Springer International Publishing, 2019. DOI: `10.1007/978-3-030-31863-5`.

ics, or it eluded theory and belonged to the realm of hydraulic engineering, like pipe- or channel flow. The discrepant results of hydrodynamics versus hydraulics illustrated the gulf between theory and practice—and turbulence was regarded as the culprit." Even to this day, these effects have "eluded theoretical analysis." When Euler's ideal flow equations were extended into the Navier-Stokes equations by accounting for fluid friction, even this new extended structure did not account for turbulence problems. Reynolds stated that "the actual behavior of fluids" had not been explained by the theory of fluids, a sentiment with which Stokes and others agreed. In the second half of the 20th century, Philip Holmes, a pioneer in dynamical systems theory, concluded that the available differential equations amounted to merely "a loose battery of theorems and methods" for addressing "specific pieces of the turbulence problem," suggesting that we cannot hope for a more unified theory. Discouraged by this lack of theoretical progress, researchers by the late 1980s had largely distanced turbulence from basic scientific research, relegating it instead to the camp of the practical and engineering sciences.

Eckert[8] identified a second culprit for the historical divergence between hydraulics and hydrodynamics: the efflux problem. In this domain as well, engineering researchers "developed methods of measurement and determined the discharge in a variety of configurations for which theoretical solutions could be achieved only in terms of empirical coefficients," ultimately failing to resolve "their historic divorce." These empirical coefficients, which were relegated to engineering textbooks rather than theoretical treatises, relied entirely on "experimental determination" and lacked any direct theoretical interpretation. Highlighting this epistemological divide, Philipp Forchheimer of the Technical University in Graz wrote in an encyclopedia of mathematical research that "[i]t should be noted that the technical tasks are not freely chosen by the researcher like the physical ones, but are forced upon him by practical need. A theoretically unsatisfactory solution, if it only proves useful within the limits within which the technique uses it, is still better than none at all." Just as with the turbulence problem, the "actual behavior" of the physical phenomenon remained unexplained by formal theory, leaving empirical, operational tools to bridge the gap.

Naturally, not all engineering research exhibits such a stark rupture between the concerns of natural science and engineering science. It is a matter of degree. When the aspects of nature that concern the theoretician align closely with the operational features of devices in their applied environments, the gap between theoretical laws and practical application remains minimal.

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[8] Eckert, "The efflux problem".

This appears to be the case, for instance, in theories of signal modulation[9] and electric circuits[10]. While more must eventually be explored regarding this specific class of theories, their existence does not alter the two facts most relevant to our inquiry. First, engineers are primarily driven by empirical laws (relying on varying degrees of theoretical underpinning); while theoretical content is highly desirable, its absence never discourages engineering progress. Second, in cases where the divergence between science and engineering is pronounced, the root cause is almost always a class of phenomena exhibiting the "actual behavior" of the system—the messy, real-world dynamics that are of utmost practical interest to the engineer. Although Reich and Kline challenge the depiction of scientific and engineering communities as completely separate mirror images, they do not deny the divergent pulls of the two enterprises. They acknowledge the fundamental tension between theoretical and practical concerns—specifically regarding a class of observational phenomena—even if these enterprises are ultimately carried out by overlapping communities.

Channell[11] identifies a similar tension—and corresponding methods of resolution—to the one highlighted in Eckert's study, specifically within the domains of prime movers and the strength of materials. Rankine made significant contributions to these areas by providing "engineers with the needed connections between the engines and structures they had to deal with and the scientific laws that never quite seemed to fit the phenomena of the real world." As was the case with hydraulics, analyzing such "a system combined theory and practice since the laws of heat relied more heavily on formal theoretical concepts, while an understanding of the properties of steam relied on experimental and practical data." In the study of the strength of materials, this empirical method allowed Rankine to "predict how the material might act in a real structure," a direct echo of Reynolds's concern with the "actual behavior" of systems. Just as hydraulics relied on empirically determined coefficients to manage complex phenomena, Channell explains that Rankine viewed technology as conceptually distinct: "technology is more concerned with materialistic concepts, such as the properties of actual bodies. These

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[9] For discussion, Leonard S. Reich. "Irving Langmuir and the Pursuit of Science and Technology in the Corporate Environment". In: *Technology and Culture* 24.2 (Apr. 1983), p. 199. ISSN: 0040165X. DOI: `10.2307/3104037`. eprint: `JSTOR`

[10] Similarly, Kline (Ronald Kline. "Science and Engineering Theory in the Invention and Development of the Induction Motor, 1880–1900". In: *Technology and Culture* 28.2 [1987], pp. 283–313. eprint: `ProjectMuse`. URL: `muse.jhu.edu/pub/1/article/889394`)

[11] David F. Channell. "The Harmony of Theory and Practice: The Engineering Science of W. J. M. Rankine". In: *Technology and Culture* 23.1 (Jan. 1982), p. 39. ISSN: 0040165X. DOI: `10.2307/3104442`. eprint: `JSTOR`.

properties are based on direct observations or experimental testing of the materials themselves. Because science and technology evolved out of different conceptual frameworks, discoveries in one area cannot be readily applied to the other area."

In summary, the historical divergence between natural and engineering sciences reveals a distinct prioritization of epistemic goals. Engineering theories consistently give primacy to formulating empirical laws capable of accounting for the "actual behavior" of phenomena of immediate practical concern. Rather than advancing strictly within a mature theoretical framework designed to explain the empirical laws themselves the engineering enterprise prioritizes operational utility. Consequently, engineering science readily develops and relies upon empirical generalizations to satisfy observational demands, frequently functioning and progressing without the need for foundational theoretical principles.

3 Theoretical and Observational in Engineering Theories

In this section, I will establish a distinction based on the results obtained in previous section. It will be done within a specific notion of scientific theories, that of the RV. And I begin by briefly outlining the specific sense in which I utilize the RV. I will also articulate the reasons for its selection and, drawing entirely on existing literature, provide a justification for its technical standing in light of prominent philosophical criticisms. For the purposes of this paper, the RV is not employed as a comprehensive descriptive account of scientific practice, but rather as a precise logical apparatus for rational reconstruction. It is not suggested that other notions of scientific theories cannot be used to analyze the above distinct nature of theories and laws within engineering and natural sciences, but only that this is the most fruitful one given its dual-level conception of language—which distinguishes between theoretical and observational vocabularies— and hence, provides the necessary structural tools to formalize the historical divergence identified in Section 2. Also, following primarily Carnap, this study maintains that such theoretical principles cannot be derived solely from observational data.[12] The paper as a whole is limited in its scope within these two presuppositions.

The RV is frequently conflated with the syntactic view and criticized for supposedly advocating first-order predicate logic as the sole tool for formal-

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[12] For instance, Carnap. (Rudolf Carnap. *An introduction to the philosophy of science.* Ed. by Martin Gardner. new ed. New York: Dover publ, 1994, p.228)

ization. However, Carnap allowed for entailment. And as Lutz,[13] and others have noted, “for some, higher order logic is effectively already set theory, and set theory can be axiomatized in predicate logic anyway, so it is possible to use all of set theory in the Received View.” Indeed, Carnap’s later writings actively employed modal logic, as well as set theory, for axiomatizing space-time topology.

Beyond the requirement of a sufficiently rich formalism, a central tenet of the RV is the dual-level conception of language, which distinguishes between observational and theoretical (or non-observational) vocabularies. As Carnap noted, this is not a sharp dichotomy but rather a matter of degree; nevertheless, “the difference is so great that there is no debate about the radically different nature” of these concepts and terms[14]. Addressing this, Demopoulos notes that while Putnam[15] “persuasively argued that unreconstructed scientific terms and sentences are not easily classified as observational or theoretical... Putnam’s observation, though correct, is largely irrelevant to the successful execution of a reconstructive program like Carnap’s. To make the distinction in the language of the reconstruction, it suffices that we can distinguish between observable and unobservable events, their properties and relations.”[16] Thus, depending on the reconstructive context, a term may function as theoretical in one instance and observational in another. It is a critical point for our present study that while Carnap sometimes preferred the labels “elementary” and “abstract,” as we will treat certain uninterpreted engineering science terminology as observational. It is vital to emphasize that Carnap never restricted “observational” or “elementary” terms to natural language. In a formal reconstruction, a term can be technical and still function as observational.

A further issue concerns the semantic interpretation of symbols within these frameworks, distinct from their syntactic definitions. Summarizing the position defended by Przelecki[17], Lutz explains that the central idea “in the

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[13] Sebastian Lutz. “What’s Right with a Syntactic Approach to Theories and Models?” In: *Erkenntnis* 79 (S8 Aug. 2014), pp. 1475–1492. ISSN: 0165-0106, 1572-8420. DOI: `10.1007/s10670-013-9578-5`.

[14] Carnap, *An introduction to the philosophy of science*.

[15] Hilary Putnam. *Mathematics, Matter and Method: Philosophical Papers.* 2nd ed. Cambridge UP, Apr. 30, 1979. DOI: `10.1017/CBO9780511625268`, ’What Theories Are Not’.

[16] William Demopoulos. “Carnap on the rational reconstruction of scientific theories”. In: *The Cambridge Companion to Carnap.* Ed. by Michael Friedman and Richard Creath. 1st ed. Cambridge UP, Dec. 20, 2007, pp. 248–272. DOI: `10.1017/CCOL9780521840156.012`.

[17] Marian Przelecki. *The logic of empirical theories.* Monographs in modern logic series. London: Routledge & K. Paul, 1969. 108 pp.

approach is to initially use a structure in the sense of Tarski semantics for the interpretation of the observational terms, and interpret the theoretical terms by the class of structures whose interpretation of the observational terms is identical to that of the initial structure, and which are models of the sentences in the object language that provide the interpretation of the theoretical terms."[18] Thus, in the absence of correspondence rules (C-rules) linking them to observational vocabulary, theoretical terms remain strictly "partially interpreted." Moving forward, I will rely on two principles that have remained constant despite the evolving details of semantic interpretation in RV accounts. First, "that observational terms can be explicitly defined in theoretical terms, but not vice versa" (*Ibid*). Second, in a theoretical account, physical features must be defined as theoretical (often mathematical) structures, with physical properties representing values within those structures; observational properties are then subsequently defined in terms of phenomenally available qualities.

The next feature—upon which the core issue of our study turns—is the distinction between empirical and theoretical laws. Carnap states, "Theoretical laws are related to empirical laws in a way somewhat analogous to the way empirical laws are related to single facts," and inherently, "Theoretical laws are... more general than empirical laws." Consider the expansion of a heated metal rod: when the governing law is expressed using quantities and properties measurable by relatively direct techniques, we are operating strictly in the realm of empirical laws. Yet, to explain these empirical laws themselves, we "must introduce a theory—the atomic theory of matter—and we are quickly plunged into atomic laws involving concepts different"[19]from those found in the empirical domain.

Empirical laws generally assume the logical form $\forall x(Px \rightarrow Qx)$. They explain specific facts through the following deductive form (or yield a high inductive probability in statistical systems):

$$L_1, L_2, \ldots, L_n, C_1, C_2, \ldots . C_n \vdash F$$

In this schema, L stands for the covering laws, C denotes the particular circumstances or initial conditions, and F represents the explanandum—the specific fact being explained. Just as empirical laws logically entail single facts, we employ broader, more robust theoretical frameworks to explain a

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[18] Sebastian Lutz. "The Received View and its images". In: Flavia Padovani and Adam Tamas Tuboly. *The Routledge Handbook of the History of Philosophy of Science After Kant.* 1st ed. London: Routledge, Dec. 16, 2025, pp. 198–208. DOI: `10.4324/9781003381051-21`.

[19] Carnap, *An introduction to the philosophy of science.*

class of empirical laws. This encapsulates the distinction between theoretical and empirical laws, delineating both their explanatory targets and their respective vocabularies. Furthermore, this deductive-nomological structure constitutes the CL model of explanation.

The appeal and relevance of adopting this framework for our study can now be explicitly stated. Engineering research typically produces empirical laws formulated in a language that is directly interpreted within an observational context (the "actual behavior"). These are often expressed in terms of empirical coefficients, for example, which lack any direct theoretical interpretation and do not map onto a theoretical structure. Although the RV is an account of scientific theories, it also accounts for empirical laws and this type of observational vocabulary. Consequently, adopting the RV allows us to analyze both science and engineering along the axis of the empirical/observational (which serves to explain isolated facts) versus the theoretical (which serves to explain and unify those empirical laws), enabling a structural comparison of the two domains - specifically regarding the relationship between their explanatory power and logical strength.

Now, let's reconsider the fluid mechanics scenario described by Eckert within the context of the divergent methodological pulls of distinct epistemic goals in engineering and scientific enterprises.

Let T_{fm} designate the set of sentences of a natural science theory that failed to account for turbulence and efflux problems at any stage of its development. T_{fm} can account for a class of empirical laws and principles, such as the Navier-Stokes equations. Let E_{proper} collectively designate the enumerable set of such laws accounted for by T_{fm}; for illustration, let there be three such laws: E_1, E_2, E_3. The non-logical language of T_{fm} includes the theoretical vocabulary (*T-vocab*) and the observational vocabulary (*O-vocab*). Both are linked through correspondence rules (C-rules), which can be seen as postulated laws themselves, establishing relations between theoretical principles and observational elements.

Further, let E_4 and E_5 (collectively designated as E_{extra}) be the sentences of empirical laws established by engineers to account for turbulence and efflux problems. The union of these,$T_{fm} \cup E_{extra}$, forms the hydraulics account of the "actual behavior" that eluded T_{fm} alone. E_{extra} might share some *T-vocab* and *O-vocab* with T_{fm}, but crucially, these laws also employ extraneous observational vocabulary O_{extra} that lacks any interpretation in T_{fm}, as there are no C-rules bridging these empirical terms to the theoretical principles and structures. This O_{extra} is observationally interpreted via physical measurement techniques, typically described through empirical data tables. Thus, while $T_{fm} \cup E_{extra}$ can now account for the class of phenomena of interest to engineers, it does not constitute a natural science theory, because

E_{extra} remains unexplained by T_{fm}.

Given this framework, we can now delineate the relationship between logical strength and explanatory power within these two accounts: the practical domain of hydraulics $T_{fm} \cup E_{extra}$ and the scientific domain of hydrodynamics (T_{fm}). The concept of logical strength employed here derives from a foundational principle in model theory and possible world semantics: if A entails B, but B does not entail A (meaning A is strictly logically stronger than B), then A is true in fewer structures—and in at most as many possible worlds—as B. It follows that if a theoretical framework (T_{fm}) is strictly logically stronger than the empirical laws it entails (E_{proper}), the models satisfying those empirical laws will form a superset of the models satisfying the theoretical framework. We define the cognitive content of a theoretical law as the specific set of structures excluded by the strongest empirical laws it entails. Therefore, a scientific theory possesses greater cognitive content than the union of its empirical laws because the set of models satisfying the theoretical structures is a strict subset of the models satisfying the empirical generalizations alone.

What is the cognitive content of an empirical law in the absence of a theory? An empirical law states that for all x, if predicate P holds for x, then predicate Q will also hold for x, i.e., $\forall x(Px \to Qx)$. The only possible worlds the empirical law excludes are those where there exists an x such that P holds but Q does not, $\exists x(Px \wedge \neg Qx)$. Therefore, in the state-description of $T_{fm} \cup E_{extra}$, the only content added is the trivial exclusion of models of this specific kind. This does make $T_{fm} \cup E_{extra}$ logically stronger than T_{fm} alone, as the set of worlds the former models is smaller. But it does so in an ad hoc way at the direct cost of explanatory power—where explanatory power can be understood as derivability, or the theoretical unity expressed through such derivability[20].

4 Conclusion

In conclusion, this paper demonstrates that the Carnapian Received View (RV) provides an apparatus for articulating the structural differences between natural science and engineering theories. By extending this conception—particularly through its dual-level distinction between theoretical and observational vocabularies—we can formally capture the methodological divergence observed historically in fields like fluid dynamics. The analysis reveals that natural science theories, such as those attempting to model fluid

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[20] Philip Kitcher. “Explanatory Unification”. In: *Philosophy of Science* 48.4 (Dec. 1981), pp. 507–531. ISSN: 0031-8248, 1539-767X. DOI: `10.1086/289019`.

motion, strive to unify these vocabularies via correspondence rules; they maximize explanatory power to account for the empirical laws themselves. Conversely, engineering theories in domains like hydraulics prioritize practical utility and the management of "actual behavior". They achieve this by integrating uninterpreted, extraneous observational vocabulary, denoted as O_{extra}. This fundamental distinction illustrates that while the two domains may overlap, scientific theories derive their cognitive content from theoretical unity, whereas engineering models achieve an ad-hoc logical strength necessary for operational success, doing so at the direct expense of such explanatory unity.

Consequently, this formal reconstruction directly addresses the central challenges of the autonomy thesis within the philosophy of technology. Rather than relying on the tacit assumption that distinct goals—"truth" versus "practical utility"—automatically guarantee distinct epistemological structures, the application of the RV establishes a precise, structural demarcation criterion. The presence and functional reliance on O_{extra} in engineering frameworks formally vindicates the autonomy of technological knowledge, proving it possesses an epistemological architecture distinct from natural science. Ultimately, this account not only clarifies the historic divorce between theoretical disciplines like hydrodynamics and practical ones like hydraulics, but it also provides a foundational framework to evaluate engineering theories on their own autonomous epistemic terms.

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