Huygens’ principle and the Michelson-Morley experiment: Reconsidering the ether hypothesis

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Abstract

The Huygens principle is applied to the propagation of plane waves from a uniformly moving source in an ideal, inviscid fluid. This simple dynamical model is shown to be consistent with the special relativistic phenomena of stellar aberration and time dilation, and can account for the null result in the Michelson-Morley experiment. These findings are consistent with the 4-vector properties of linear acoustic fields, and suggest a reconsideration of ether models for electromagnetic wave propagation.

Key words: Huygens’ principle, Michelson-Morley, ether, Special Relativity, 4-vector, acoustic Lorentz invariance
1. Introduction

The null result of the Michelson-Morley (MM) experiment is one of the most celebrated observations in modern physics.\(^{(1)}\) It led to the abrupt demise of ether theories of light propagation,\(^{(2)}\) and was later enshrined as a natural outcome of Einstein’s theory of Special Relativity (SR).\(^{(3)}\) According to SR, the lack of an observed phase shift in the perpendicular light rays of a moving MM interferometer is a natural consequence of its second postulate (constancy of the speed of light in all inertial frames). This and other predictions of SR (e.g., time dilation and the transverse Doppler effect) have been experimentally confirmed with ever-growing precision,\(^{(4,5)}\) rendering SR an uncontested foundational principle of modern physics.

This paper discusses the possibility that the second postulate of SR may be derived, by analogy with sound propagation, from a mechanical (fluid dynamical) interpretation of light travel. The null result of the MM experiment will be shown to follow as a consequence of the Huygens principle when applied to a wave source in motion. In contrast to SR, the fluid dynamical model presented here requires a preferred frame for fluid wave propagation. Nevertheless, it can still predict the phenomena of stellar aberration, time dilation and the relativistic Doppler effect in exact agreement with SR. These findings are in line with the acoustic Lorentz invariance shown by linear acoustic fields,\(^{(6-10)}\) and suggest the possibility of a fluid dynamical basis of electrodynamic phenomena.

2. Relativistic Huygens’ Principle

SR is an axiomatic theory. Its basic postulates — the equivalence of physical laws, and the constancy of the speed of light, in all inertial frames — are \textit{a priori}, kinematic assumptions. Einstein brilliantly intuited their necessity in order to impose symmetry on the electrodynamics
of bodies in motion, but he made no attempt to give a mechanistic basis for these postulates.\textsuperscript{(3)} A physical interpretation of SR may be possible, however, by considering the dynamics of wave propagation from moving sources in an ideal, inviscid fluid. Figure 1 illustrates the process of rectilinear wave formation in such a fluid. Consider the segment $AB$ of an infinite line source. If the source is at rest relative to the fluid, simultaneous firing of wave pulses along $AB$ results, trivially, in linear wavefronts propagating in a direction perpendicular to the $AB$ line (Huygens’ principle). If, however, $AB$ is moving at speed $v$ relative to the fluid medium, as shown in Fig. 1, application of the Huygens principle is more subtle and requires consideration of the relativity of simultaneity.

Figure 1(a) depicts the situation in which an observer $O$, co-moving with the line source and midway along $AB$, experiences simultaneous firing of wave pulses from points $A$ and $B$. As in the case above for a line source at rest in the fluid medium, let this simultaneity of firing events at $A$ and $B$ define the generation of a linear wavefront parallel to the line source $AB$, and perpendicular to the direction of source travel $v$, as observed in the moving frame. In the fluid, or rest frame, however, the Huygens principle dictates that the resulting (linear) wavefront, \textit{as observed in the fluid frame}, is tilted from the perpendicular by an angle:

$$\sin \theta = \frac{v}{c},$$

where $c$ is the speed of the wave in the fluid medium.

The derivation of equation (1) is based on the following simple postulate, commonly invoked to account for the dynamics of acoustical shock front formation: \textsuperscript{(7,11)}

\textit{Postulate I} — A point source in a fluid medium will generate a circular wave in the fluid frame, centered around the point of the original disturbance and traveling in the fluid.
frame at speed c, irrespective of the state of motion of the source relative to the medium at the time of the disturbance.

Postulate I can also be thought of as the definition of the existence of a preferred (fluid) frame for wave propagation.

2.1 Relativity of Simultaneity

The relativity of simultaneity follows directly from this postulate. Events that are simultaneous in the co-moving source frame (firing of wave pulses from A and B, in Fig. 1) are clearly not simultaneous in the fluid frame (where B fires after A). In order to calculate the time delay between these firing events in the fluid frame, consider the rays from A and B that travel to observer O. It follows that:

\[ A_0O_2 = c\Delta t_{20} = v\Delta t_{20} + \frac{1}{2} AB \]  
\[ B_1O_2 = c\Delta t_{21} = -\frac{1}{2} AB - v\Delta t_{21} \]

where \( X_m \) corresponds to the position in space of a generalized point source or observer, \( X \), at time \( t_m \) (e.g., \( X = A, B \) or \( O \) in Fig. 1), \( X_mY_n \) is the distance between points \( X_m \) and \( Y_n \), \( \Delta t_{mn} = t_n - t_m \) and the distance \( XY \equiv X_mY_m \). Note that these spatial and temporal parameters are measured in the fluid frame. Combining Eqs. (2) and (3), one obtains the time delay between firing events at A and B:

\[ \Delta t_{10} = \frac{AB}{c} \frac{v/c}{1 - v^2/c^2} \]

This equation is equivalent to that obtained in SR, but is here derived from a dynamical point of view (Postulate I).
2.2 Stellar Aberration

Examination of Fig. 1(a) also leads to the following geometrical relationships:

\[ A_0 B_1 = AB + v \Delta t_{10} \]  \hspace{1cm} (5)

\[ A_0 B_1 \sin \theta = c \Delta t_{10} \].  \hspace{1cm} (6)

Eq. (1) then follows by simple algebraic manipulation of Eqs. (4)-(6). This result is important, since Eq. (1) correctly accounts for the effect of stellar aberration as predicted by SR.\(^{(12)}\)

2.3 Time Dilation

The tilt in wavefront described by Eq. (1) also provides a physical interpretation of the concept of time dilation in SR. Consider a unit of time defined as the roundtrip travel time, \( t_r \), of a linear wavefront from point \( A \) on a line source \( AB \) to a reflector (parallel to \( AB \), at distance \( L \)) and then back to \( A \). If the source \( AB \) is at rest relative to the fluid medium that transmits the wave, the situation is trivial and \( t_r = 2L/c \). If, however, the line source moves through the fluid at speed \( v \), in a direction parallel to \( AB \) and the reflector, observers at rest in the fluid would measure the roundtrip time of the tilted wavefront (\( ab \) in Fig. 1(a)) as:

\[ t'_r = \frac{2L}{c} \frac{1}{\cos \theta} \].  \hspace{1cm} (7a)

Substituing for \( \theta \) using Eq. (1), one obtains:

\[ t'_r = \frac{2L}{c} \frac{1}{\sqrt{1 - v^2/c^2}} \equiv \gamma \frac{2L}{c} , \hspace{1cm} (7b)\]

which is in exact agreement with the formula for time dilation in SR. Derivation of Eq. (7) from Postulate I also implies this fluid dynamical model can account for the transverse Doppler effect, since the latter is a sole and direct consequence of time dilation.\(^{(13)}\)
Care must be taken, however, in considering the above definition of a clock, or unit time, when applied within the co-moving frame itself. Eq. (7) holds for the time dilation observed in the fluid frame from a clock in motion through the fluid, relative to an equivalent clock at rest in the fluid. This would correspond, for example, to the roundtrip travel of the fluid frame tilted wavefront $ab$ (Fig. 1(a)), from a specific source point $A$ along $AB$, to the reflector and back to the source point $A$, as recorded by a set of synchronized observers in the fluid frame. Synchronization is defined here in the SR sense of a notional grid of inertial frame observers, with clocks synchronized according to the time of travel of wave pulses between them, but with the speed of wave motion in the fluid medium – rather than the speed of light – defining the maximum speed at which information can travel, and clocks can “tick”, in the medium. As will be shown below, the tilted wavefront $ab$ observed in the fluid frame is not the same wavefront experienced by a set of synchronized observers co-moving with the line source $AB$. To demand so would imply the existence of a global time scale and the absolute simultaneity of events in all inertial frames. As seen in Section 2.1 above, though, and as expected by SR, this is not the case. One must therefore first clarify what is meant by “the wavefront as experienced in the frame co-moving with the line source $AB$”.

In order to define this, one can consider the Huygens principle as applied to the moving wave source $AB$ in the co-moving frame. Figure 1(b) shows propagation of the same circular pulses from line source $AB$ as in Fig. 1(a), as observed in the fluid frame; however, a different set of rays is highlighted ($A_0a$ and $B_1b$) which are now perpendicular (in the fluid frame) to the line source and its direction of motion, rather than tilted. What is experienced as a wavefront in the co-moving frame is not the same tilted wavefront $ab$ shown in Fig. 1(a); instead, the wavefront is experienced as being parallel to the line source, and is constituted by the tangential locus of
circular wavefronts along line \( az \), i.e., the tangent of the circular wave from source \( A \) (at time \( t_2 \) in the fluid frame) with the circular wave from source \( B \) (at time \( t_2 + \Delta t_{10} \) in the fluid frame). This is depicted in Fig. 1(b) as the tangent \( az \) between equiradial pulses from \( A_0 \) and \( B_1 \). The dashed depiction of the pulse from \( B_1 \) is meant to highlight the fact that these equiradial pulses do not simultaneously coexist in the fluid frame: the tangent \( az \) encompasses pulses at different times in the fluid frame (e.g., \( t_2 \) vs. \( t_2 + \Delta t_{10} \) for the equiradial pulses from \( A_0 \) and \( B_1 \)). The difference in fluid frame time between these pulses is worth stressing, in order not to interpret the line \( az \) as a snapshot in a stationary reference frame where simultaneity can be considered absolute.

The moving frame wavefront \( az \) is physically distinct from the wavefront perceived in the fluid frame (Fig. 1(a), tilted line \( ab \)), even though it arises from the same wave source \( AB \). The set of rays that constitute wavefront \( az \) in Fig. 1(b) propagate along a different direction in space than those that constitute wavefront \( ab \) in Fig. 1(a). This element of the fluid mechanical model of wave propagation from moving sources is alien to SR, where individual light rays undergo geometric transformation in spacetime as a function of relative motion of a light source, but ultimately conserve their identity and relation to events irrespective of choice of inertial frame. The different physical identity of the wavefronts depicted in Figs. 1(a) and 1(b) will be seen below to play an essential role in allowing for a Huygens’ principle interpretation of the null MM experiment.

It can readily be shown that the co-moving frame wavefront, \( az \), described above would be experienced in the fluid frame as the tilted locus of ray termini \( ab \), with tilt angle:

\[
\tan \alpha = \frac{v}{c}.
\]  

(8)
Note that this tilted locus does not correspond, according to the Huygens principle, to an observable wavefront in the fluid frame. Derivation of Eq. (8) follows from simple geometric arguments, and is the key to a dynamical interpretation of the null result in the MM experiment.

It follows from Fig. 1(b) that:

\[
\tan \alpha = \frac{b_z}{A_0 B_1} = \frac{c \Delta t_{10}}{AB + v \Delta t_{10}}
\]

\[
\Rightarrow \Delta t_{10} = \frac{AB \tan \alpha}{c - v \tan \alpha}
\]

\[
\Rightarrow \Delta t_{10} = \frac{AB \tan \alpha}{c - (v/c) \tan \alpha}.
\]  

Eq. (8) then follows from Eqs. (4) and (10), i.e., by recalling the condition that source points A and B are experienced as firing wave pulses simultaneously in the co-moving frame.

Having thus defined the nature of the linear wavefront perceived in the co-moving frame, it is now possible to pose the following question: What is the roundtrip time of the co-moving frame wavefront $a_z$, from a point A to a reflector and back to A, as measured in the fluid frame? This series of events is depicted in Figure 2. Line source $AB$ propagates at speed $v$ through the fluid medium, as in Fig. 1. A mirror, $M$, parallel to $AB$ and a distance $L$ away from it, reflects the co-moving frame wavefront back to $AB$. The roundtrip time, $t'_R$, will be measured in the fluid frame by a notional lattice of observers with clocks synchronized in the SR sense, as defined above.

Recall that the constituent rays of the co-moving frame wavefront move in a direction perpendicular to $AB$ in the fluid frame (Fig. 1(b)). This implies that the wavefront ray emanating from point A (at fluid frame time $t_0$, Fig. 2(a)) cannot be the same wavefront ray that returns to A after reflection from $M$ (Fig. 2(c), fluid frame time $t_z$)! The co-moving frame
wavefront ray that does return to \( A \) after one mirror roundtrip has to be generated at some other point, \( B \), downstream from \( A \) (Fig. 2(b), fluid frame time \( t_1 \)). It follows from Fig. 2 that:

\[
t_R'' = \Delta t_{20} = \Delta t_{10} + \Delta t_{21}.
\]  

(11)

In order for the return of the perpendicular ray from \( B_1 \) to be spatially and temporally coincident with \( A_2 \), it must follow that:

\[
\Delta t_{21} = \frac{2L}{c} = \frac{AB_1}{v} = \frac{AB}{v}.
\]

(12)

Since firing events \( A_0 \) and \( B_1 \) are simultaneous in the co-moving frame, \( \Delta t_{10} \) is given by Eq. (4) and yields:

\[
t_R'' = \frac{AB}{c} \frac{v/c}{1-v^2/c^2} + \frac{2L}{c}.
\]

(13)

Substituting for \( AB \) using eqn. (12) then leads to:

\[
t_R'' = \frac{2Lv}{c^2} \frac{v/c}{1-v^2/c^2} + \frac{2L}{c}
\]

\[
= \frac{2L}{c} \left( \frac{v^2/c^2}{1-v^2/c^2} + 1 \right)
\]

\[
\Rightarrow t_R'' = \frac{2L}{c} \frac{1}{1-v^2/c^2} \equiv \gamma^2 \left( \frac{2L}{c} \right).
\]

(14)

To clarify the difference between Eqs. (7b) and (14), consider the same line source \( AB \) as above, moving through a stationary fluid medium in which is embedded an infinite grid of synchronized (in the SR sense described above), stationary observers. Let moving point \( A \) emit a flash of red light when it first fires a circular wave pulse into the fluid medium. A synchronized observer \( X \) at rest in the fluid medium, whose spatial coordinates overlap exactly with \( A \) at that moment, records the time (in the fluid frame) at which this event takes place \( (t_0) \). Now, let
moving point $A$ emit another flash of red light at the time when it perceives the emitted linear wavefront (analogous to line $az$, in Fig. 1(b)) return to it from the mirror $M$ (Fig. 2(c)). A second synchronized observer $Z$ at rest in the fluid medium, whose spatial coordinates overlap exactly with $A$ at this later moment, records the time (in the fluid frame) at which this event takes place ($t_z$). The time interval between red flashes, as measured in the fluid frame ($\Delta t_{20} \equiv t''_R$) will be given by Eq. (14). Note that this is similar to the standard SR formula for time dilation (eqn. (7b)), but contains an additional factor of $\gamma$.

By contrast, let the grid of stationary synchronized observers, at rest in the fluid frame, independently measure the roundtrip time of the linear wave emitted by the moving source $AB$ (from moving source point $A$, to the mirror $M$, and back to $A$). These synchronized observers would determine the emitted wavefront to be tilted relative to line $AB$ (as in Fig. 1(a)). A synchronized observer $X$ at rest in the fluid medium, whose spatial coordinates overlap exactly with $A$ at that moment, records the time (in the fluid frame) at which this event takes place ($t_0$) and instantaneously emits a green pulse of light. Another synchronized observer $Y$ at rest in the fluid experiences the first return of the (tilted) fluid frame wavefront to line $AB$, coincidentally with the arrival of moving point $A$ to the same spatial coordinates as $Y$. Let $Y$ record the (fluid frame) time of this event ($t_t$), and let it instantaneously emit a second flash of green light. The time interval between green pulses, measured in the fluid frame ($\Delta t_{10} \equiv t'_R$), would be given by Eq. (7b) and thus be shorter than the time between red pulses ($t''_R$) by a factor of $\gamma$.

This thought experiment concerns a proper time interval: emission of a linear wavefront from point $A$ (along a moving line source $AB$), to a reflector $M$ and back to the same point $A$. The Huygens principle provides a means to precisely define this interval in microscopic,
dynamical terms (Figs. 1(b) and 2). Note that despite the additional factor of $\gamma$, unfamiliar to SR, in the time interval $t_R$ recorded by fluid frame observers (Eq. (14)), the net result of the Huygens principle analysis is in agreement with SR, in the sense that $t_R^\prime/t_R = \gamma$, i.e., a clock moving through a fluid medium is experienced to run slower by observers in a co-moving frame (set of red pulses) by a factor of $\gamma$ relative to the period of the same clock experienced by observers at rest in the fluid frame (set of green pulses).

2.4 Michelson-Morley Experiment

Finally, it can be shown that the null result of the MM experiment follows from Postulate I, and is therefore not inconsistent with an ether (fluid) model of light propagation. Figure 3 shows application of the above Huygens’ principle analysis to the MM experiment. In this case, $AB$ represents a linear segment of a plane wave light source traveling at speed $v$ relative to the vacuum (or ether). We will consider the rays that constitute the linear wavefront as observed in the co-moving frame, and track their paths and time of travel in the preferred (ether) frame. By analogy to Fig. 1(b), the light wavefronts perceived in the co-moving frame of the MM experiment are emitted at right angles to the direction of motion through the ether, and their constituent rays (e.g., $A_0a$ and $B_1b$) are then split by the 45° beamsplitter, $S$, in directions parallel and perpendicular to the direction of motion. The pair of circles shown in Fig. 3 are the wave pulses generated by source points $A$ and $B$ as observed at a specific time, $t_2$, in the stationary, ether frame. The parallel and perpendicular co-moving mirrors, $M$ and $N$, are located at an equal distance $L$ from where the ray terminus $a$ first strikes the beamsplitter (at time $t_2$). As will be seen below, this distance $L$ is a physical invariant, and applies equally to the
moving and the ether frames, i.e., the fluid dynamical model will account for the null result in the MM experiment without imposition of a Lorentz contraction.

Consider now the propagation of ray termini $a$ and $b$, in the ether frame, after interaction with beamsplitter $S$. Recall that these rays constitute part of the linear, perpendicularly propagating wavefront observed in the co-moving frame. It can be shown that the parallel beamsplitter reflection from source $A$ (ray $adz$) recombines at the beamsplitter at a later time ($t_4$) exactly in phase with the perpendicular ray from source $B$ (ray $bez$). According to Postulate I, the time of travel of ray $adz$, as measured in the ether frame, is given by:

$$\Delta t_{adz} = \frac{2L}{c} \frac{1}{1-v^2/c^2} \equiv \Delta t_{42}. \quad (15)$$

This is the familiar expression for the parallel-ray travel time in the standard treatment of the MM experiment. For the perpendicular ray $bez$ in Fig. 3, the time of travel is:

$$\Delta t_{bez} = \frac{2L}{c} + \Delta t_{10}. \quad (16)$$

The condition for perfect phase matching of these two rays (i.e., a null MM result) is given, therefore, by equating these two time intervals:

$$\frac{2L}{c} \frac{1}{1-v^2/c^2} = \frac{2L}{c} + \Delta t_{10}$$

$$\Rightarrow \Delta t_{10} = \frac{2L}{c} \left( \frac{1}{1-v^2/c^2} - 1 \right)$$

$$= \frac{2L}{c} \frac{v^2/c^2}{1-v^2/c^2}. \quad (17)$$

From Fig. 3, it follows that:

$$\tan \alpha = \frac{bz}{az} = \frac{c\Delta t_{10}}{vc\Delta t_{42}} = \frac{c\Delta t_{10}}{\sqrt{2L} \frac{1}{c} \frac{1-v^2/c^2}}$$

$$= \frac{2L}{c} \frac{1}{1-v^2/c^2}.$$
\[
\Rightarrow \Delta t_0 = \frac{2L}{c} \frac{\nu/c}{1 - \nu^2/c^2}\tan \alpha .
\]  

Finally, substituting for \( \tan \alpha \) using Eq. (8) one recovers Eq. (17), thereby proving that wave pulses emitted from point sources \( A \) and \( B \) (simultaneous in the co-moving frame) recombine in perfect phase in the MM experiment! By extension of this argument to all point sources along the linear wave source \( AB \), it follows that the co-moving frame wavefront \( az \) will be reconstituted in perfect phase in the MM experiment, thereby accounting for the lack of interference effects (null result) observed in this classic experiment. Note that this proof did not require imposition of a Lorentz contraction.

This analysis revives the concept of a preferred frame – an absolute fluid medium (ether) – for sustaining electromagnetic wave propagation in vacuum. It predicts time dilation in a system in absolute motion relative to the ether, in exact mathematical accordance with the transformation formula of SR (Eq. (7b)), but it does away completely with the concept of a Lorentz contraction. The latter is only a necessity in a theoretical framework in which the in-phase reconstituted light rays in the MM experiment are assumed to arise from the same source point in space (e.g., \( A_0 \) in Fig. 3). That assumption is at the core of traditional interpretations of the MM experiment, as well as in SR, and leads to the perceived need of an absolute spatial (Lorentz) contraction along the direction of motion. The model presented here, however, proposes that constructive interference between rays originating at different spatial positions (\( A_0 \) and \( B_1 \)), and at different times in the ether frame (\( t_0 \) and \( t_1 \)) are responsible for the null phase lag observed in the parallel and perpendicular split wavefronts in the MM interferometer. This novel interpretation retains the time dilation intrinsic to Lorentz transformations (LT), but
challenges the traditional identity of the light rays which constitute the recombined wavefront in the MM experiment.

In related, but independent, work, Gjurchinovski has also derived the formula for relativistic aberration of light (Eq. 1) based on the Huygens principle.\textsuperscript{(14)} His paper does not consider, however, a detailed analysis of the MM experiment based on that model. In addition, Gjurchinovski invokes the Lorentz contraction when generalizing his model to the case of a plane wave source tilted relative to its direction of motion.

3. Acoustic Lorentz Invariance

The relativistic Huygens’ principle analysis presented above is consistent with the 4-vector properties of linear acoustic fields.\textsuperscript{(8)} It has been known for some time that the dynamics of sound propagation from a uniformly moving source bears a striking resemblance with relativistic electrodynamics. Blokhintsev first noted that the dynamics of a moving sound source agrees, in many respects, with the Liénard-Wiechert retarded potential dynamics of a moving electrostatic charge.\textsuperscript{(6)} More recently, Stanzial \textit{et al.} have developed a 4-vector (acoustic energy-momentum density) analysis of linear acoustic fields.\textsuperscript{(8)} Their treatment confirms the Lorentz form invariance of the acoustic wave equation under what they term an “acoustic Lorentz transformation”, i.e., by drawing an exact mathematical analogy with relativistic electrodynamics and simply replacing the speed of sound for the speed of light.

It is worth noting, however, that there is a lack of clarity in the acoustics literature regarding the precise form of the acoustic LT equations. In Stanzial \textit{et al.}, an exact correspondence with standard LT equations is implied.\textsuperscript{(8)} However, other treatments of the dynamics of uniformly moving sound monopoles,\textsuperscript{(9,10)} including the seminal work by Morse and Ingard,\textsuperscript{(7)} make use of
an additional factor of $\gamma$ in the transformation equations (Eqs. (20) below) in order to achieve form invariance with the acoustic wave equation from a stationary source, i.e.:

$$\begin{aligned} x' &= \gamma^2 (x - vt) \\
y' &= \gamma y \\
z' &= \gamma z \\
t' &= \gamma^2 \left( t - \frac{v}{c^2} x \right) \end{aligned}$$  

(20)

Further work is required to clarify whether the set of Eqs. (20) implies a breakdown of a strict mathematical analogy between moving sound monopoles and moving electrostatic charges or whether, despite the extra factor of $\gamma$, one may still treat the transformation properties of the acoustic wave equation as exactly Lorentz invariant. In light of the discussion above on time dilation (Section 2.3), whether a certain acoustic LT transformation requires, or not, an additional factor of $\gamma$ may reflect subtle differences in how proper time intervals are defined in the underlying dynamical equations, i.e., whether Eqs. (7b) or (14) are relevant in defining the periods of moving clocks. The Huygens principle analysis presented here may thus provide physical insight into, and reconcile, the LT variants currently invoked in the acoustics community for treating the dynamics of moving sound sources.

Exact acoustic Lorentz invariance would imply a sonic equivalent of the MM experiment would also give a null result. A corollary of this statement is that an ether interpretation of the MM experiment would indeed be possible, if one assumed electromagnetic radiation required a fluid medium (ether) in which to propagate i.e., if one were to adopt a sonic analogy for the electromagnetic wave equation from a radiation source in motion through the ether. Such an interpretation would be in line with the relativistic Huygens’ analysis presented in this paper.
4. Fluid Dynamical Analogies of Electromagnetism

Revival of an ether-based interpretation of electromagnetic wave propagation could account for the rich history of fluid mechanical analogies in the field of electrodynamics. A hydrodynamic treatment of magnetism, first developed by Helmholtz and Lord Kelvin in the mid nineteenth century,\(^\text{15,16}\) survives to this date in the well-established parallels between magnetostatics and vorticity-free fluid flow.\(^\text{17}\) Advances in the field of Bose-Einstein condensate dynamics have more recently extended these analogies to electrodynamic, as well as magnetic, phenomena. Most notably, Popov has shown that “a two-dimensional system of phonons and vortices is equivalent to relativistic dynamics”, with the phonons and vortices assuming the corresponding roles of photons and electric charge in electrodynamics.\(^\text{18}\) In line with these findings, superfluid vortices have also been predicted to decay via sound emission upon acceleration, in exact analogy to Larmor radiation.\(^\text{19}\)

A conjectural, but particularly intriguing, parallel between fluid mechanics and electrodynamics is the apparently relativistic mass-energy relationship associated with the hydrodynamic mass of a vortex, \(M_{\text{hydro}}\):

\[
M_{\text{hydro}} = \frac{E_{\text{vortex}}}{c^2}\quad(21)
\]

where \(E_{\text{vortex}}\) is the static (or rest) energy of the vortex and \(c\) is the speed of sound in the fluid medium.\(^\text{18,20}\) It would be of great interest to explore this relationship as a possible dynamical basis for Einstein’s analogous and celebrated formula.

A revival of ether theory opens up the possibility that these “analogies” are more than mere mathematical curiosity and expediency, reflecting instead a common (fluid) dynamical basis to electromagnetic and hydrodynamic phenomena. Besides allowing for a reinterpretation of
relativistic electrodynamics, ether models of space could also deepen our understanding of quantum phenomena. Various fluid dynamical models, for example, have been proposed to account for the quantum properties of electromagnetic radiation. Hunter et al. have presented a solitonic solution to Maxwell’s equations which can properly account for quantization of photon energy and angular momentum, and is consistent with the Heisenberg uncertainty principle.\textsuperscript{21} de Nigris has adapted the concept of a plasma fluid to vacuum polarization, and also shown that application of Maxwell’s equations to vacuum perturbations can reconcile the corpuscular and wavelike features of electromagnetic radiation.\textsuperscript{22} More recently, Lekner has derived solutions to the propagation of angular momentum in sound pulses, and shown that in the short wavelength limit (i.e., significantly smaller than the spatial extent of the pulse) the energy and angular momentum of the sound pulses is quantized in exact analogy with conventional behavior of phonons in fluid media.\textsuperscript{23} In light of a revived ether model, the latter model could shed significant physical insight into the quantization of energy and angular momentum in photons.

5. Experimental Tests of Acoustic Lorentz Invariance

The fluid mechanical model of SR presented here may be tested by experiment. A sonic analogue to the MM experiment, for instance, could be readily performed. A null result from such an experiment has indeed been presented by Feist in 2001, although confirmation of this result in a peer-reviewed publication is still pending.\textsuperscript{24} Stanzial et al. have also measured the acoustic radiation pressure along the inside of an organ pipe, under steady sound conditions, and found it to be in good agreement with their 4-vector acoustic field model.\textsuperscript{8}
6. Conclusion

In summary, an acoustical model of electromagnetic wave propagation has been presented, based on application of the Huygens principle to a uniformly traveling plane wave source. The model provides a dynamical basis for the relativity of simultaneity and dilation of time in inertial frames, and can account for the null result of the MM experiment without imposition of a Lorentz contraction. These findings are in line with the acoustic Lorentz invariance shown by linear acoustic fields from uniformly moving sound sources. Experimental verification of a sonic analogue to the MM experiment would support this hypothesis, and pave the way for a major paradigm shift in modern physics: the revival of ether theory, and the possibility of a fluid dynamical basis for SR and fundamental physical forces.

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(a) $\sin \theta = \frac{v}{c}$

(b) $\tan \alpha = \frac{v}{c}$

Figure 1.
Figure 2.
Figure 3.
Figure 1. Huygens’ principle applied to a rectlinear wave source, \(AB\), with velocity \(v\) relative to the fluid medium. Source points \(A\) and \(B\) are experienced as firing wave pulses simultaneously in the co-moving source frame (i.e., by co-moving observer \(O\)). (a) Tilted wavefront (tangent line \(ab\)) experienced in fluid (rest) frame from \(AB\) source; (b) Transverse wavefront (tangent line \(az\)) experienced in co-moving source frame from \(AB\) source. The line \(ab\) in this case represents the locus of constituent rays of the \(az\) moving frame wavefront, as observed at a given time \((t_2)\) in the fluid frame.

Figure 2. Time dilation in a relativistic clock illustrated by the roundtrip time of a wavefront emitted and received back by a linear source \(AB\) in motion (as in Fig. 1). \(M\) is a mirror, and \(L\) is its distance from \(AB\). Figs. 2(a), (b) and (c) show snapshots of the circular wave pulses emitted by source points \(A\) and \(B\), in the fluid frame, at various fluid frame times \((t_0, t_1\) and \(t_2)\). (a) Source point \(A\) emits wave pulse \((t = t_0)\); (b) source point \(B\) emits wave pulse \((t = t_1)\); (c) perpendicular ray from source point \(B\) strikes source point \(A\) \((t = t_2)\).

Figure 3. Relativistic Huygens’ principle applied to the Michelson-Morley experiment. The figure shows circular wave pulses and rays of light \((adz \) and \(bez\)), in the fluid (ether) rest frame, arising from a moving plane wave light source \(AB\). The null result of the Michelson-Morley experiment can be attributed to perfect phase matching between rays \(adz\) and \(bez\). Key: \(M\), \(N\) = mirrors; \(S\) = beamsplitter.