n°09 ...freeze!

tunnel vision

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Wind Tunnel Bulletin n° 09
Research Focus in
Transdisciplinarity at Zurich
University of the Arts

ISBN 978-3-9524260-8-1

We are grateful to the Archives of the Max Planck Society for their kind permission to reproduce their material. We also wish to thank Susanne Uebele and Florian Spillert for their kind support in the archive. Last but not least, we thank Werner Große for supporting our research on The Institute for Scientific Film (IWF).

Images:
Cover and pp. 168–262: screenshots taken by the editors and designers; Frontispiece: Text accompanying the IWF release version of Ludwig Prandtl's flow film *Entstehung von Wirbeln bei Wasserströmungen*; pp. 274–275: screenshots by Florian Dombois and Christoph Oeschger; p. 278: screenshots by Oliver Gaycken.

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Imprint

The Wind Tunnel Bulletin is published by the Research Focus in Transdisciplinarity at Zurich University of the Arts.

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wind tunnel bulletin n° 09, june 2019

The Experiment in the Age of Its Technological Reproducibility

Written in the mid-1930s, Walter Benjamin's essay *The Work of Art in the Age of Its Technological Reproducibility* serves us as both a substrate and an impetus for exploring the following question: What happens to an experiment when it is captured on camera and then reproduced, evaluated and distributed as a film?

This Bulletin issue approaches the question in two parts: The first part takes a pictorial form (pp. 168–262, published in December 2018) by presenting—in accordance with the print medium—single frames and sequences of frames from scientific films. In doing so, we concentrate on fluid dynamics. Since the 1900s, scientific films have been produced at various fluid-dynamic research institutes worldwide for the contact-free recording of dynamic and potentially turbulent flows. One of these institutes, which embraced the medium of film with considerable effort and skill, and used it in applied and basic research as well as in research commissioned by the military, was the Kaiser Wilhelm Institute for Fluid Dynamics in Göttingen, Germany. Ludwig Prandtl headed the institute from 1925 until 1946. Our single frames and image sequences are taken from films from Prandtl's institute. The selection of images is also indebted to our discovering this rare material in the Archives of the Max Planck Society in Berlin, whose permission to reproduce these images is gratefully acknowledged.

For the second part (pp. 263–282, published in June 2019) we invited several authors to reflect with us on the first part with its images and react to our question: What does film do to an experiment or even to the experiment in general? We are overwhelmed that all authors whom we asked agreed to contribute and think with us. Thank you very much! And thank you, dear reader, for joining us too. We will now raise the curtain, switch on the camera and … *freeze!*

REICHSANSTALT FÜR FILM UND BILD IN WISSENSCHAFT UND UNTERRICHT
HOCHSCHULFILM C 1/1936 u. C 2/1936

Entstehung von Wirbeln bei Wasserströmungen.

Von Prof. Dr. **L. PRANDTL.**
(Direktor des Kaiser-Wilhelm-Instituts für Strömungsforschung, Göttingen).

Die Aufnahmen sind nach der von Prof. Dr. AHLBORN in Hamburg ausgearbeiteten Methode gewonnen. Die Objekte werden mittels eines Wagens durch das ruhende Wasser eines Tanks geschleppt; die Aufnahmekamera fährt bei der Mehrzahl der Bilder mit dem Objekt mit, wodurch der Eindruck entsteht, als ob das Objekt in Ruhe wäre und das Wasser strömte. Die Bewegung wird dadurch sichtbar gemacht, daß feine Aluminiumflitterchen auf das Wasser gestreut sind. Bei einigen Versuchen ist absichtlich der Wasserspiegel um ein Weniges höher eingestellt als der obere Rand des Versuchsobjektes, so daß hier die Wasseroberfläche ein wenig gegen den Rand zu geneigt ist. Hierdurch reichern sich die Aluminiumteilchen in der Nähe des Objekts an und es werden dadurch die Flüssigkeitsteile, die ursprünglich am Objekt angelegen haben, als Stellen dichterer Bestreuung besonders gekennzeichnet.

Die dargestellten Vorgänge sind mit wenigen Ausnahmen „ebene Strömungen", d. h. die Objekte reichen bis zum Grund des Wassertanks herunter, und es ist die Bewegung in allen waagerechten Schichten dieselbe wie die sichtbar gemachte Bewegung der Oberfläche.

T e i l 1 befaßt sich mit der Entstehung von Wirbeln und mit der künstlichen Beeinflussung der Wirbelbildung (Literatur z. B. L. PRANDTL: „Abriß der Strömungslehre", III. Abschn. § 6 u. 7; auch „Magnuseffekt und Windkraftschiff", Naturwissenschaften 1925, S. 93). Die ersten 6 Szenen zeigen die Entstehung von Wirbeln an runden Körpern, zunächst an einem Kreiszylinder (einmal im Gesamtbild und einmal in Großaufnahme die Gegend, in der die Wirbel entstehen), dann an einem großen länglichen

Körper, von dem nur die hintere Hälfte gezeigt wird. Die Strömungsgeschwindigkeit ist in diesem Fall besonders klein gewählt, um eine genügend dicke Grenzschicht zu erzielen, deren Umkehr infolge des Druckanstiegs gut beobachtet werden kann. In allen drei Fällen ergibt sich zunächst eine Strömung ohne Wirbel (Potentialströmung); später führt die Rückströmung in der Grenzschicht zur Wirbelbildung. Nach Ausbildung des Hauptwirbels ist eine zweite Ablösung (Bildung eines Sekundärwirbels) zu beobachten. Die nun folgenden Aufnahmen mit dem elliptischen Zylinder zeigen, daß bei sehr flach gewölbten Oberflächen die Strömung sich nach der Ablösung durch Wirbelbildung wieder anlegen kann, wobei die Strömung von da ab turbulent verläuft. Bei sehr kleiner Geschwindigkeit („unterkritischer Strömung") ist die Wirbelbildung zu schwach und die Strömung bleibt abgelöst.

Die nächsten 4 Szenen zeigen die Wirbelbildung an scharfen Kanten, die in diesem Fall sofort mit dem Beginn der Bewegung einsetzt. Der hinter einem Tragflügel gebildete „Anfahrwirbel" hat als Gegenwert der Zirkulation um den Tragflügel eine besondere Bedeutung in der Tragflügeltheorie [Abriß II, § 10 und III, § 15*) und 16*)]. Wird der Tragflügel kurz nach dem Ingangsetzen wieder angehalten, so entstehen zwei gegenläufige Wirbel, die sich nach den Helmholtzschen Sätzen (Abriß II, § 11) selbständig weiterbewegen. Die nächsten zwei Szenen zeigen Vorgänge am rotierenden Zylinder, wo durch Beeinflussung der Grenzschicht durch die mitbewegte Oberfläche der eine der beiden Wirbel unterdrückt wird. Man erkennt den Anfahrwirbel und den ihm entsprechenden zirkulatorischen Anteil der Umströmung, der nach dem Abstoppen der Zylinderdrehung als freier Wirbel sichtbar wird. Durch Absaugen der Grenzschicht läßt sich die Strömung ebenfalls beeinflussen. Es unterbleibt auch hier die Ablösung und es können dadurch sehr ungewohnte Strömungsbilder, z. B. eine wirbelfreie Ausbreitung der Strömung in einem stark erweiterten Kanal, erzeugt werden.

Der z w e i t e T e i l bringt Anwendungen auf die Strömung durch Krümmer, Hohlräume und Verzweigungsstücke. In der

*) In der III. Auflage (1941) § 17 u. 18.

Reprint of an unchanged reprint of the text accompanying Ludwig Prandtl's flow film *Entstehung von Wirbeln bei Wasserströmungen*.

Introduction: The Experiment in the Age of Its Technological Reproducibility

Sarine Waltenspül
(Media historian, Zurich)

Flow and film

In 1895, at the latest, film and cinema, and from 1903 flow research and aerodynamics, became important driving forces of social, political, and technological changes and transformations.[1] As different as 'film' and 'flow research' may seem at first glance, both are devoted to the same phenomenon: the study of the ephemeral, of movement.

While the importance of photography for the study of fluids has already been discussed in depth—especially in case studies on Ludwig Mach, Etienne-Jules Marey and Friedrich Ahlborn—this Bulletin issue investigates the role of films in flow research, films which stem from a later period than the first photographic flow visualizations, namely from the 1920s and 1930s.[2] In terms of media history, that was a time when the medium of film was established both technologically and societally, and with regard to the history of science it was a heyday of applied hydro- and aerodynamics and a time after the "cinematographic turn" in the sciences.[3]

After many initial difficulties, film and flow found each other in the 1920s, and film was used both in fluid-dynamic basic research and in applied research. This was the case especially when turbulent phenomena were investigated. Sometimes the films were evaluated qualitatively and/or quantitatively, sometimes they were used in the lab, or they were shown at congresses.[4] It therefore seems inappropriate to a priori differentiate the films systematically based on their intended functions as laboratory films[5] *or* as scientific attractions at congresses. The epistemic and aesthetic potential of the visual will not be contrasted here, but confronted, parallelized, and put up for discussion.

The reproduced experiment, flow and film

The camera was suitable par excellence for examining fluids in general, because it produced fewer unintended turbulences than other measuring procedures and because it made the uniqueness of turbulent phenomena reproducible and consequently not only visible, but also analyzable. As a mathematically feasible description of turbulence had not been developed yet, one was dependent on qualitative 'descriptions' of the phenomena and experimental study of the processes. The films printed in the image part were deployed in order to understand and explain turbulence and eddy formation. Taking these films and still images extracted from them as a point of departure, we, the editors, have invited other authors to contemplate from the perspective of their respective discipline these or other flow images or flow films in the light of the following question: How did experiments change due to the possibility of technological reproducibility that emerged at the beginning of the twentieth century? Or to put it differently: What happens to an experiment when it is made reproducible on film (recording) and is reproduced in film (playback)?

In this introduction, I do not want to provide an overview of possible answers to this question, given the character of the Bulletin as a publication medium for unfinished ideas and topics that give us food for thought, but from my own perspective put forward a few (and partly bold) hypotheses in connection with flow films recorded in the context of scientific experiments. First, in conjunction with Walter Benjamin's hypothesis on the change of human sensory perception in the face of photo-filmic reproduction technologies that he presents in his essay *The Work of Art in the Age of Its Technological Reproducibility.* Second, with regard to the debates on reproducibility in science. Third, I would like to link the two points to the relationship between aesthetics and politics based on the example of a flow film. Fourth, I would like to broach the subject of how research films and images can contribute to an understanding of scientific practices.

Needless to say, the debates on these topics are complex. Consequently, I will only address aspects that I deem relevant in connection with flow films. Furthermore, I will refer in particular to a flow film that Ludwig Prandtl and his collaborators made in the 1920s and that throughout the rest of the century and beyond traveled through different contexts. Mario Schulze, the coeditor of this volume, and I are currently investigating the history of this film.

1. Aura and aesthetics

First to Walter Benjamin, for whom the medium of film holds both potentials and dangers. According to Benjamin, the achievements of film, as opposed to painting, include its greater analyzability due to its greater capacity for isolation. These characteristics would foster the "the mutual penetration of art and science."[6] For Benjamin, the photo- or film-technical reproduction of an artwork, on the other hand, also posed dangers: It would change the artwork. The artwork would lose its "here and now," its uniqueness, its aura. Benjamin writes: "By replicating the copy many times over, it [the reproduction technology] substitutes a unique existence with a mass existence."[7]

Now, my hypothesis is that in the case of the experiment and regarding the flow films in the image part, Benjamin's assertion that an artwork loses its aura when it is technically reproduced seems to be reversed: The singular event of an eddy is not only isolated and becomes analyzable, but also undergoes an auratization and an aestheticization due to its cinematic reproduction. Lisa Cartwright points out that the "seductive and exciting" part of the visual in scientific images is underestimated, because the visual is often criticized as being overrated. In the tradition of feminist visual studies, she writes: "To dismiss the visual as overrated is to overlook the role of pleasure as an important factor in scientific process."[8] In the case of flow images, and above all flow films, this "role of pleasure" can be expanded and concretely related to a potentially auratic share of the visual.

2. Quantification of flow and film

Reproducibility und replicability is a much-discussed topos, both when it comes to historical and ontological definitions of the experiment, and to the debates conducted regarding scientific large-scale projects under the slogan "reproducibility crisis" or "replication crisis."[9] In the latter case, it is about quality criteria and validity—in other words, about the comparability of measurements and the resulting data. The indecisiveness regarding the choice of terms in the debates (a third option would be repeatability) is already a sign of the difficulties involved. While certain voices differentiate between the concepts, others call for their being used synonymously.[10] Harry Collins uses the terms repeatability and replicability synonymously and calls them "the touchstone of common sense philosophy of science." He notes, however, that it is of central importance to differentiate the idea of replicability from the "complexities of its practical accomplishment."[11]

Regarding films of experiments, I would like to suggest that the term reproducibility is preferable to replicability and repeatability, and in the following I will develop this idea using Prandtl's film as an example. The term reproducibility also encompasses—going beyond the primary meaning of repetition, which all three terms have in common—the production of something material: a thing, a commodity, a film. And thus also in the case of the experiment, reproducibility goes straight to the sinister heart of the twentieth century: capitalism. I would like to show this in two steps: in a quantification first of flow and then of film, and then by bringing this together with a hypothesis formulated by Mary Ann Doane. For the cinematic reproducibility of the experiment (which consists both in the production of a reproducible trace and in the reproduction of this trace in each playback of the films) enabled a higher circulation of the experiment, enabled it to "travel,"[12] and as a consequence also new perspectives for a quantification.

First, to the quantification of flow. With the introduction of the film camera in flow research, the streamline resulting from photographic bulb exposure gave way to the particle images of cinematographic short exposure. These particle images basically made it possible to pursue individual particles, which in turn formed the basis for the quantification of flow.[13] In 2007, two DLR scientists, Christian Willert and Jürgen Kompenhans, analyzed Prandtl's film by means of particle image velocimetry, and referred to it as "probably some of the oldest time-resolved particle image velocimetry (PIV) image sequences."[14]

Second, to the quantification of film. The film experiment not only made the phenomena shown quantifiable, but also itself *as* research film and "substitutes a unique existence with a mass existence," as it were.[15] Back in the early 1920s, in the course of the programmatic writings on the German-language school film movement, people were called upon to "introduce film as a substitute or supplement of the experiment."[16] Films were subsequently distributed for teaching and classroom purposes in the 1930s, due among other things to the introduction of 16 mm safety film and financed via contributions levied for teaching materials. These technical and structural prerequisites formed the basis for the Reich Office for Teaching Films (RfdU, later RWU),[17] an internationally unparalleled large-scale production and distribution system in fascist Germany whose goal was to standardize the German educational system.

So, what does film do to the experiment? Mary Ann Doane describes cinema as a "crucial participant in an ongoing rethinking of temporality in modernity." This temporality, which came to society also to a significant degree on account of cinema, can be viewed as a function of capitalist modernity "with its emphases upon distribution, circulation, [...] quantification, and rationalization."[18] Taking Prandtl's flow film as an example, one of many possible answers can be given to the question of what film can do to the experiment: The cinematic reproducibility makes the flow potentially (with Prandtl) or actually (with Willert/Kompenhans) quantifiable; and it enabled the distribution and increased circulation of research films by the RfdU. The distribution, circulation, and quantification of flow and film are parts of this—our—capitalist modernity.

3. Aestheticization of politics, politicization of aesthetics

In the case of flow films, this meeting of potential or actual quantification of flow through film, of films themselves, and the abovementioned aestheticization of flow yields a toxic mixture. For Prandtl's flow film can also be interpreted as an "aestheticization of politics"[19] in fascism, as described by Walter Benjamin. In any case, the flow film was included in the RfdU's media catalog parallel to the emergence of Benjamin's text, and listed henceforth as "C1." The film—one of the "most sought after educational films there is"[20]—served to standardize the educational system, popularize aerodynamic research, and promote the enjoyment of flow films.

Now, how can the history of such a film be written without continuing to write the history of National Socialist aestheticization in a latently affirmative way? How can aestheticized politics be handled at all? One suggestion would be to look to Benjamin. For a closer look reveals that the seeming power over the phenomena of the camera as a scientific, quantifying instrument, and the power over research films of the RfdU's distribution system, stand in contrast to the powerlessness of Prandtl and others vis-a-vis the material. This attests, it can be argued further, to a certain autonomy of the film. This film was able to avoid instrumentalization—and not only instrumentalization by Prandtl or the RfdU, but also by many others. The continual denial of a clear definition seems to have been motivation, as it were, to move, or travel, to other contexts, for example to the educational films in reaction to the sputnik crisis produced at MIT, to film competitions, such as the ones organized at flow visualization symposia, or into the context of the research project *Luftbilder/Lichtbilder.* This points to an epistemic openness of the material, an openness that can be specified in more detail elsewhere and which—according to the hypothesis—lies in something or is related to something that can be called 'aesthetic surplus.' By an aesthetic surplus I mean the hard-to-grasp visual share of images and films that goes beyond the visualization of the phenomena and that affects the viewer. I think that this aesthetic surplus is related to the auratization of flow and turbulences by film: that precisely through the reproducibility, tribute is paid to the singular flow in its uniqueness; that it is precisely film that gives ephemeral phenomena authority, to use another of Benjamin's terms: and that perhaps precisely this aesthetic, aura, authority and autonomy of film enabled it to travel out of the context of its instrumentalization by fascism. So perhaps the acknowledgement of these four a's of the film—its aesthetics, aura, authority and autonomy—gives us contemporary historical researchers the possibility to encounter, or even to stand up against, an "aestheticization of politics" by deploying a Benjaminian "politicization of aesthetics." To this end, the relationship between the epistemic and aesthetic content of the film both regarding its production context in all the "complexities of its practical accomplishment,"[21] and regarding the many different reception contexts must be determined and the respective associated political interests investigated.

4. Whereof one cannot speak, thereof one must show

To conclude, I would like to talk about the basic stimulus for this Bulletin and ultimately for the entire research project behind it.[22] The aim of the project was to pay well-deserved tribute to the epistemic and aesthetic potential of film, both in the form of approaches rooted in the history of media and science as well as artistic approaches. I would like to briefly address the first with regard to the Bulletin as well as Peter Galison's call for a *visual science and technology study* and the acknowledgement of the visual "as source, evidence and form of reasoning."[23] Galison asks: "Can there be a kind of knowledge, an epistemological contribution from film that supplements and enriches our understanding of science-in-practice?"[24]

If film is used not only to document experiments but also as a fixed component of the experimental setting, an understanding of science-in-practice must also encompass an understanding of specific cinematic practices and techniques. These

can be read in the films and in their immobilization in the form of single frames. To quantify the flow, both "profilmic"[25] measuring instruments were used (such as clocks and yardsticks) as well as decidedly filmic measuring techniques (such as interval lights to measure time in the image or time markers at the edge of the image), most of which were recorded on the "filmographic,"[26] that is, the material level of the film. In addition to these intended traces, however, it is often the unintended traces that provide information about experimental, film and archive practices. In a close viewing and close reading of these traces, the films can become sources, evidence and forms of reasoning.

Both sections—the image and text part—can be viewed as independent approaches to the experiment in the age of its technological reproducibility. Likewise, in line with the *… freeze!* suggested as a title for this issue, the possibilities and limits of translating the moving picture into the print medium will be explored in image and text form: For what is absent is movement and thus exactly that which constitutes both film and flow.

Fluid Dynamics with Benjamin

Mika Elo
(Artist, Helsinki)

Walter Benjamin has become known as a thinker who welcomed the disappearance of aura in the age of technical reproducibility of artworks, that is, in the historical situation where it started to become evident that the concept of artwork is intrinsically tied to the socio-technical conditions of art. Benjamin, however, used the term aura in many different contexts and its meaning varies accordingly. Further, Benjamin never wrote about the disappearance of aura. Instead, he thematized its decay and pointed out how and why auratic structures should be destroyed in specific historical constellations.

At the same time, Benjamin thought that the experience of aura can be positively invested, as it offers a starting point for questioning habitual patterns of thinking. In short, aura is a symptom of the historical shifts in what he called the "medium of perception." It is a relational phenomenon and cannot be reduced to a quality that an object has or does not have. It is a weave to be deciphered; it makes something that was never written readable. If aura is not invested with reactionary desires, it functions as an estranging effect with forward-looking potential.

At the core of Benjamin's reflections on aura is the question of whether and how experience in the strong sense (*Erfahrung*) is still possible in industrial society. When the framing conditions of everyday life change more and more rapidly, things look back at us from an unexpected angle more often than not. Benjamin thematized this in terms of a shift from "first technology" organized around the human experiencer to "second technology" that decenters the human being. If first technology creates experiences in the horizon of a mastery of nature, second technology shapes experiences as the interplay between nature and society.

Here, experiment plays a key role. When the supposedly natural ground of experience is questioned, the playroom of experience appears as a constellation of components in scientific terms: parameters. In this space, a single stroke doesn't count; it does not form the concept of an artwork nor does it offer scientific evidence. Things require framing. Elements and traces need to be arranged in ways that enable montage, sampling, mechanized tests and statistical analyses. In this peculiar weave of time and space, art escapes the realm of beautiful semblance and becomes a societal organ, and, in this respect, comparable with science.

Societal organs or *dispositifs* have ontological consistency only insofar as they originate meaning. But how should one think about the origin in the playroom of experience when everything builds on arrangements? In this context, Benjamin brings us to fluid dynamics. For him, origin is a historical category that nevertheless has nothing to do with genesis. The term origin names the process through which the components or parameters of an experiential situation come together and become distributed in relation to each other. Origin is an eddy in the stream of becoming.

As Benjamin points out, the camera speaks to the eye from the navel of dreams. It transforms collective imagination into an issue of technological arrangements and art into elemental politics. If the Dadaists turned the artwork into a missile by surfing in the maelstrom of experience, the image part of Bulletin n° 09 targets the virtual witness of an experiment by aestheticizing its parameters. The flow is over; let turbulence prevail.

Reproduced Flows and Auratic Films

Mario Schulze
(Science historian, Zurich)

Few aspects of Walter Benjamin's work (and perhaps of the humanities as a whole) are as prominent and have been as widely discussed as his thesis on the loss of aura in the age of film and photography.[27] My aim here is not to add yet another footnote to the exegesis of Benjamin's aura. Rather, I want to raise the question of the potential that a transfer of his concepts to experiments—more specifically, to fluid-dynamic experiments—might have.

The epistemic role of the films from the Kaiser Wilhelm Institute for Fluid Dynamics (KWI), from which some screenshots are printed in the image part of Bulletin n° 09, is largely undetermined or at least not easy to determine. In part, they were developed in the hope of obtaining measurement data. But this was achieved, if at all, only to a very modest extent. Regarding the films, the institute director and filmmaker Ludwig Prandtl laconically observed that, apart from some statistical mean values, he and his colleagues "could not learn much from them yet."[28] While many of the films were not dealt with directly in any scientific publication, let alone in a theory, but quickly disappeared in the archives, a few sequences—despite the failed measurements—attracted a lot of attention. Prandtl showed the sequences under the title *Hydrodynamic Film* at conferences and lectures around the world, using them as evidence for his boundary layer theory. Later, the recordings were re-edited to make an educational film and as such presented in manifold ways until well into the 1970s in the classrooms of high schools, colleges, and universities. Without discussing the complex history of this film (which I am currently investigating with the coeditor, Sarine Waltenspül) in detail here, one aspect seems key to me: Although the epistemic function of this specific film, as well as other films from the KWI, was often unclear and these films scarcely offered help for measurements, Prandtl subsequently showed an almost obsessive interest in this film. Not only did he bring it with him as a reel on lecture tours for years on end, what is more, he never forewent the opportunity to re-edit and rework the film, adding recordings, double frames, etc.

In any case, how can this history of fluid-dynamic film images from the KWI be related to Benjamin's thoughts on the aura? And can we then learn something about the initial question of the Bulletin: What happens with flow experiments in the age of their technological reproducibility?

In his *Arcades Project*, Benjamin juxtaposed the concept of aura with the notion of trace: "Trace and aura. The trace is appearance of a nearness, however far the thing that left it behind may be. The aura is appearance of a distance, however near the thing that calls it forth may be. In the trace, we gain possession of the thing; in the aura, it takes hold of us."[29] This intriguing pair of concepts—so I claim—can also be applied to the genesis of the aforementioned flow film recordings: The film was initially produced to gain possession of a non-stationary flow. The experimental setting consisting of a water channel, marker particles, and a camera was designed to create a reproducible and evaluable trace of the flow. But the phase of trace production in the experiment was followed by another phase. It seems as though subsequently the film increasingly took hold of its producers (and recipients). In any case, Prandtl became very attached to the film and made it part of his legacy. Was it the aura of the film that triggered Prandtl's obsession? While the first aspect—of trace production in experiments—has been discussed often in science history (above all by Hans-Jörg Rheinberger), the second—the auratic power of produced scientific images—is far less widespread although it has been considered in feminist visual science studies (e.g. by Lisa Cartwright): Scientific images and perhaps especially film images can provoke fascination, concerns and fears and thus become the driving force of a quest to find a way to justify the belief in the evidentiary value of images.

It may be vexing to apply the concept of aura in this way to scientific flow films. After all, the interpretation of Benjamin's texts that was common for a long time implies that there is a loss of aura in the face of the possibilities of filmic reproducibility. However, in his examination of aura, rather than attempting to establish a clear concept, Benjamin on the contrary aimed to scrutinize the possibilities of experience in a technical-mediatized world. In no way did Benjamin see contemplation of films and photos as categorically ruling out auratic experiences. In some places, for example in his reflections on early photography, technical reproduction is even the basis for the perceptibility of an aura. To formulate my thesis in the form of a question: Cannot flows of all things belong to those phenomena whose auratic radiation is etched out or at least reinforced by filmic reproduction? The word aura itself stands etymologically for a flow. It comes from the Greek and means "air" or "breath." Furthermore, in Greek mythology "Aura" is the goddess of the morning breeze. But the no less mythological present also provides examples of the auratic effects ascribed to flow patterns: Advertising (especially for the latest media technology) is full of them—recently, for example, iPhone 10 advertising.

A transient and thus time-dependent flow, as the films discussed here show, is characterized by uniqueness and unapproachability. Each intervention would be disruptive and any exact reproducibility is excluded. The only method that can be used to gain possession of it is optical recording. But the recording exposes a discrepancy between theoretical prediction and the actually visible progression of the flow. This gap between film and prediction drives us, and already drove Prandtl, to view these images again and again and, in addition, to search for ever-new recordings and devices. Or to put it differently: The film engenders a hope that takes hold of us. The hope that someday the devices can predict the remembered movement, the past future.

According to Jimena Canales, Benjamin's writings present knowledge and media history with the task of focusing on how the unconscious guides the experimental sciences and the people who practice them.[30] I wanted to pick up on this and, based on Prandtl's films, suggest how Benjamin's concepts can help us grasp the effect that the images and films—created using scientific devices—have. I would like to make a plea not only to ask which practices were connected with the production of films and images and which theoretical insights accompanied their contemplation and comparative evaluation (as praxeological science studies research has done for 30 years), but also what they trigger in the scientists operating the devices.

Mimesis and Experiment. Walter Benjamin on Charles Ferdinand Ramuz

Kyung-Ho Cha
(Literary scholar, Bayreuth)

According to Walter Benjamin, modernity is distinguished by its experimental character. With the help of science and modern technology, modern humans are capable of entering into a new relationship with nature, whereby the idea of mastering nature has been replaced by the notion of dealing playfully with it.

Benjamin describes this paradigm shift from a mastery of nature to play as a change from mimesis to experiment. Mimesis is the original principle of technology. Benjamin understands technology as the totality of technical instruments and practices on which people's relationship to nature is based. The so-called first technology, which is rooted in the cult of magic, is based on imitation, through which nature is supposed to be tamed and controlled. Mimesis produces an artificial semblance that pretends to be nature. The origin of art, according to Benjamin, lies in magic practices. The experiment, on the other hand, is the principle of the so-called second technology, which has its origins in modernity. Science and modern technology help people produce a new kind of nature. Benjamin regards this second technology as progress in the history of humankind, as it enables people to emancipate themselves from nature and extends the capabilities of the human body. He emphasizes the experimental and playful character of the second technology describing play as an "inexhaustible reservoir of all the experimenting" of the second technology.[31]

In the third of a total of five different versions of his artwork essay, there is a footnote in which Benjamin discusses the role of science and technology for the development of modern art. The footnote contains ideas that are important not only because they help us understand the essay, but also because they aid our comprehension of his overall art theory. In the footnote, he sketches the main features of his aesthetic theory, which at the same time claims to be a theory of modernity. At the end is a quote that the preceding theoretical considerations seem to move towards. Benjamin quotes a passage from an essay by the Swiss writer Charles Ferdinand Ramuz that was published in October 1935 under the title "Paysan, nature" in the journal *Mesure*.

He says: "We are currently witnessing a fascinating process. The various sciences, which up to now have each operated alone in their special fields, are beginning to converge in their object and to be combined into a single science: chemistry, physics, and mechanics are becoming interlinked. It is as if we were eyewitnesses to the enormously accelerated completion of a jigsaw puzzle whose first pieces took several millennia to put in place, whereas the last, because of

their contours, and to the astonishment of the spectators, are moving together of their own accord."[32]

"These words," Benjamin continues in the footnote, "give ultimate expression to the dimension of play in the second technology, *which reinforces that in art*."[33] Regarding the citation and its interpretation, it should be pointed out that Benjamin does not comment any further on Ramuz' considerations and does not discuss conclusions that can be drawn from them. Ramuz uses the metaphor of the "puzzle" to describe the current state of the sciences. He notes that the traditional boundaries that have been drawn between the sciences are dissolving and the individual sciences are rapidly amalgamating into one universal unified science. Ramuz compares this scientific historical process with a jigsaw puzzle in which the universal unified science corresponds to the complete puzzle picture.

Benjamin sees this combination of science and technology as standing for "the dimension of play in the second technology, *which reinforces that in art*." According to him, the process taking place in the sciences and technology is playful and experimental, because the goal is no longer to imitate nature, but to create a new relationship between people and nature with the help of the second technology. Benjamin refers to this new relationship as "scope for play" (Spiel-Raum)[34], in which the relationship between humans and nature is no longer determined by necessity, but stands under the sign of freedom. Within this scope of play, people experiment and play with nature. Benjamin interprets the process that Ramuz describes using the metaphor of the puzzle as experimental play with nature, whereby the individual sciences are combined with one another. What is important is the relative clause "which reinforces that [i.e. dimension of play; note KC] in art": In Benjamin's view, the development of the natural sciences and technology has had a substantial impact on modern art, which in parallel with modern sciences has turned away from the principle of mimesis in order to freely experiment with its objects. He relates Ramuz' remarks to film, which in his artwork essay Benjamin intended to establish as a new art form. Film, he writes, would not have been able to come about without the interaction of "chemistry, physics, and mechanics."[35] Only when the natural sciences and technology, rather than following the model of nature, transcend their traditional limits and enter into new combinations, do the conditions exist for its genesis.

Film, which in his opinion has a strong influence on art because it reinforces the latter's turn away from mimesis and toward experimental practices, is for Benjamin a phenomenon that is paradigmatic for modernity in two respects: On the one hand, it emerged from the playful synthesis of different sciences. On the other, it embodies the principle of the second technology, which in an experimental way produces new art forms that are no longer based on the principle of mimesis.

Authenticity/Truth in Film 1936/1951: A Fictive Interview

Anja Sattelmacher
(Science historian, Berlin)

In 1936, Walter Benjamin published his famous essay on the artwork in the age of its reproducibility, in which he describes in detail how the emergence of mass media favored the loss of authenticity in art and, in addition, strengthened fascist tendencies in society. In 1951, Gotthard Wolf, the founder of the Institute for Scientific Film (IWF) in Göttingen, held a lecture on the truth content of scientific film. What is the situation with the notions of truth and authenticity in film? Are they interchangeable, both understood as meaning the same thing, so shortly before and after World War II? Can their positions be harmonized or do they have nothing in common? This text has a made-up Benjamin recipient, Dorothe A., and an imagined IWF employee, Lorenz K., enter into a fictive dialog.[36] It is an intellectual game that aims to question whether Benjamin's thoughts on film could possibly prove to be valid when applied to the history of scientific films.

L.K.: Dorothe, it's great that you are willing to take part in this conversation. Walter Benjamin and Gotthard Wolf lived in different spheres and at different times. As a Jew and an intellectual, Benjamin fled the National Socialists and committed suicide in exile in Spain in 1940. Wolf, the head of the science department of the Reichsanstalt für Film und Bild in Wissenschaft und Unterricht (Reich Institute for Film and Images in Science and the Classroom, RWU), devoted himself to technology and science in the 1930s, and later, from 1956 to 1975, was the director of the Institute for Scientific Film. He never commented on political issues. But both of them thought about the important characteristics of film. Benjamin describes in great detail why in the 1930s film became an instrument that pressed itself on the masses and that promoted an "aestheticization of politics," ultimately culminating in fascism. Wolf, too, in his writings after World War II, pointed out that film should not use any effects that generate optical illusions, because otherwise its "truth content" would be corrupted. Do they both mean the same thing when they speak of authenticity and truth?

D.A.: Lorenz, first I would like to explain in more depth what this authenticity is all about. Benjamin understood aura as "the unique appearance of a distance, however near it may be." Such an aura is tied to the "here and now." It cannot be repeated or reproduced, and cannot be depicted. That makes it so unapproachable and gives it "cult value." But in a certain sense photography and film represent the exact opposite. After all, technical reproducibility is inherent to their techniques; without a reproduction of the different image sequences there can be no film projection and no photographic print. And the mass reproduction of film works has entirely economic reasons: Since film production is so expensive, it is only worthwhile when the product is seen by as many viewers as possible, in other words, consumed. In film, any form of authenticity disappears "not least because the performance of the actor is split up into a series of episodes that can be assembled. In particular, lighting and its installation require that the representation of an event, which on the screen appears as a swift, unified sequence, is filmed in a series of separate takes, which may spread over hours in the studio." Film belongs to the realm of 'beautiful semblance'.

L.K.: But if I may briefly interrupt for a moment: Wolf wrote the following on this matter: "When film recordings are made, recording technology, copying technology, and reproduction technology are involved. Each of these technologies has its effect. These include, for example, distortion of optics, distortions through optical balance, film shrinkage effects, and so on." Only when these technical possibilities are misused is the truth content of the recording impaired. This is the case, for example, when there is an optical illusion, or with effects of time transformation, that is, fast motion and slow motion. Wolf, too, was aware that there is something suggestive about every image, especially moving images. At the same time, however, he believed that these undesired, distorting effects could be avoided: "Through the arrangement of the recording equipment and through the design, one must strive to turn viewing into perception [a word which the author intentionally spells out in two separate parts in German here: *Wahr-Nehmung*, in the sense of "truth-taking", or "appropriating-the-truth," note by transl.]. This peculiar deep perception as intellectual appropriation is closely connected to truth content." Those recordings that come closest to a perfect image of nature would then have the greatest truth content.

D.A: These remarks on the truth content of film remind me a little of the discussions about photography in relation to painting carried out around 1900, regarding the question of which medium can reflect nature most faithfully. Looking back, I think that Wolf's words have to be understood in the light of the early postwar period, when it was important to avoid any suspicion of manufacturing propaganda through film. When I think about the relationship between film and politics in the 1930s, then I indeed associate it with the aforementioned "aestheticization of politics" problematized by Benjamin, which I still consider very dangerous. Let me explain what Benjamin meant by this in more detail: The crisis of civil democracies that he experienced in the 1920s and 1930s was due in part to the kind of self-presentation that came into practice then. The rulers represented themselves vis-à-vis the representatives. Benjamin put it this way: "The parliament is his [the politician's] public! Innovations in recording equipment now enable the speaker to be heard by an unlimited number of people while he is speaking, and to be seen by an unlimited number shortly afterward. This implies giving priority to presenting the politician before the recording equipment." This results, to put it hyperbolically, "in a new form of selection before an apparatus, a selection from which the star and the dictator emerge as victors."

L.K.: Yes, and Benjamin was absolutely right, and that's why Wolf also pleaded clearly for "using sound cautiously in the guise of the explanatory word in scientific recordings, as long as the sound is not an integral part of the recorded object." Ultimately, however, I believe that Benjamin and Wolf meant two completely different kinds of film: While Benjamin mainly refers above all to the feature film, Wolf primarily addresses the scientific film. The latter is less concerned with self-presentation than with the documentary observation and description of plants, animals, people, microorganisms and machines. So perhaps we should bear in mind that while Benjamin speaks of film, Wolf actually means documentation in a more restricted sense. For him, the film recording is not so much the reflection of an artistic performance, but rather the conducting of a scientific experiment in front of the camera. After all, Wolf asserts that the film recording should not be grasped as the pure reflection of scientific results, but as an experiment whose outcome can be uncertain. One need only think of recordings of plants over a long period, which subsequently, when they are played back in fast motion, make certain growth processes visible. Or recording bacteria through a microscope.

D.A.: You see? – and here I believe, is the common ground between them. Benjamin also thought a great strength of film was that it was able to bring to light the optical unconscious by showing things that are not visible to the naked eye. He wrote: "One of the revolutionary functions of film will be to demonstrate that the artistic and scientific uses of photography which hitherto usually were separated are identical."

L.K.: Benjamin's remark can be understood as a direct invitation to found Wolf's scientific film encyclopedia, the *Encyclopaedia Cinematographica* (EC), which Wolf launched in the same year that the text cited here was published. "Based on stringent scientific criteria," a systematic recording of the animal world should be made by scientific film. The contents should include locomotion, behavior, reproduction, and the development of living organisms. Later, even inorganic movement processes (of steel, minerals, etc.) and human movement sequences were included in the EC.

D.A.: Lorenz, Wolf's reflections on the truth content of the scientific film in no way contradict Benjamin's view regarding the loss of authenticity due to the emergence of reproductive (mass) media. At the same time, however, I do not believe that an absolute truth exists which a film could reveal. Benjamin would have agreed. In his opinion, any kind of film was a form of alienation, and he saw the best possible answer to the misuse of cinematography by fascism in the "politicization of art." However, as far as I can tell, there were no renewing, avant-garde approaches in the arts in German postwar history—an observation that gives one food for thought.

The Roots of Experiments

Olivier Chazot
(Physicist, Brussels)

Science looks at nature, but also overlooks it. Science tests, measures, and investigates nature. And science talks and writes (a lot) about nature. Models, laboratories, computers, research programs and even scientific revolutions are constantly at work to build our vision of nature. But how does it find its way in us?

In the scientific process, experiments are central. They are an essential way of scrutinizing and organizing the empirical environment. Experiments are situated at the border between the known and the unknown. They are designed based on the representation we have of natural phenomena in order to question them and enrich our knowledge about nature. An experiment in a laboratory always aims at understanding something that is outside of the laboratory. It is an image of nature, yet at the same time a reference that goes beyond it. But what is this image composed of? Is there still part of nature in it? Does it capture enough of the empirical world?

At the dawn of modern fluid dynamics, Ludwig Prandtl, in 1920, recorded films of experiments he conducted in his laboratory using a water channel to study and explain the aerodynamics of airfoils as well as the behavior of flows over two-dimensional profiles. He produced images of natural phenomena in order to understand the physics of flow. To investigate this particular situation, it would help to consider what those images are, what they contain and how they correspond to our view of nature. These pictures of flows come from a series of reproductions of different kinds that can be described as follows:
1. Reproduction of a similar flow: The real flow, which corresponds to a flight situation, for instance, is reproduced in a setup at laboratory scale. To say that the flow is similar in the experiment means that it is governed by the same system of equations, even if the natural phenomena occur at different scales.
2. Reproduction of the same flow: The flow must be able to be reproduced in another experiment, in a different lab, in order to represent nature in a general sense. Any experiment must be repeatable to confer its universal character. The flow might present some local differences, but its main characteristics and parameters must be respected exactly.
3. Reproduction of an analogous flow: The flow is reproduced on film with a camera; it can also be projected on a screen, in real time. In this way,

the flow is transformed into another physical phenomenon in which its characteristics can be observed (though perhaps not all of them). The flow, as a physical image, is then considered analogous. When these images are recorded as a film, this corresponds to a measurement in which the kinetic aspects of the flow have been captured. They are easier to determine in this form.
4. Reproduction of an identical flow: The flow, as a film, can be reproduced in a duplication process. This flow is identical in the different copies of the film. The exact same sequence of images of the flow is replicated. Not much is added at this level, as a characteristic of film is that it exists in series.
5. Reproduction of an equivalent flow: When the flow is reproduced on a digital camera, it presents a different situation. In this case, the images of the flow are not transposed onto another natural phenomenon but are digitized as a collection of numbers representing discrete states. On its digital image, the flow is projected onto a numerical space and in this form is considered equivalent to the natural one. It becomes, in essence, a text: a series of binary numbers from which it can be recomposed, but also decomposed.

The point of this short note is not to discuss all these distinctions in detail, but to comment on how we capture natural phenomena through experiments and the images we record of them. Reproduction appears at many levels in this operation, and we would like to question this connection in the age of mechanical reproduction, following Walter Benjamin's analysis.

In his essay, Walter Benjamin points out that natural objects, which are even less vulnerable in some respects than artworks, are subject to the risk that their aura will decay when they are mechanically reproduced. With this concept, he intends to show that reproduction can depreciate the authenticity of the phenomena and affect its presence and ampleness where it may appear in a more complete reality. Benjamin evokes the same concern for the task of the translator when an achieved form passes into another language.

Indeed, science is strongly linked to a mechanical view, and more generally to a technical one, as science looks at nature the way it talks about it. All the reproductions we have considered, in the example of a flow in a laboratory and in their corresponding films, are mechanical reproductions and thus something that could affect the aura according to Walter Benjamin. Moreover, the technical vision is unconsciously adopted in our common view as it covers up the strangeness of the world. It puts nature at our disposal while wiping out the intensity of its presence contained in its aura.

However, reproduction is a risk to be taken in experiments. It is an exile from its original land; it is even prone to peril that natural objects can barely withstand. The aura disappears when natural phenomena are torn off their ground. With mechanical reproduction, nature is uprooted, exposed to a violent process, and it might perish if it is not replanted in soil where it can find its way back to a secret life.

Walter Benjamin never directly blames reproduction itself, but rather the uses that can be made of it. Yet reproduction is not a catastrophe, inasmuch as experiments include parts of nature; it is mostly our view that reduces it. In his attempt to define the aura of an object, Benjamin writes of "the unique apparition of a distance, however close it may be." This strangely corresponds to Thomas Aquinas's definition of prophetism: The "apparition of a distance" regarding a reality, as a germ, that must be discerned in order to see what is going to be generated. It is in this sense that we have to look at experiments, they are intrinsically mechanical reproduction but they have also to be perceived as experiences that live on further in us. What might be left over, through overly strict technical treatment, must be able to find inward refuge. Reproduction could thus eventually generate something new. The natural phenomena apprehended in our research must find their roots within ourselves to engender our essential understanding of nature.

Film in Experiment, Experiment in Film

Hans-Jörg Rheinberger
(Science historian, Berlin)

Late nineteenth-century chronophotography—prominently represented by Eadweard Muybridge in Great Britain, Leland Stanford in America, and Etienne-Jules Marey in France—demonstrated the analytical potential of photographs taken in rapid succession for the analysis of motion sequences of animals and people. Around the same time, Ernst Mach and Peter Salcher showed the analytical potential of snapshots of bullets travelling through the air at high speed. Serial photographs and snapshots have complex technical preconditions. Their development is, however, not dealt with in the following considerations. Rather, the aperçu presented here revolves around the epistemological contextualization in the early twentieth century of one of the follow-ups of serial photography, namely cinematography or film. In the experimental sciences, it was adapted as a phenomenological technique to analyze motion sequences in water channels and wind tunnels constructed specifically for this purpose. I limit myself here to just a few brief remarks.

In this context, the film camera is basically taken and analyzed as a technical device that is inserted into an experimental setup designed to produce flow phenomena. The goal is to be able to make these phenomena—or parts of them—visible in the first place, and secondly, to subject them to analysis in accelerated, decelerated, or immobilized form. Generally, to this end, the motion phenomena at issue must first be produced. As mentioned, since the early twentieth century, this was primarily done in special spaces: in wind tunnels or water channels set up expressly for this purpose. Particularly when aerodynamic phenomena were to be visualized, one had to add smoke or dust, for example, to make them visible. When it comes to hydrodynamic phenomena, streaks and swirls could be enhanced by a soluble dye. Gaston Bachelard dubbed such procedures "phenomenotechniques."

In a second step, the movement has to be fixed deploying another medium, that of film, and then in this transposed form further resolved and represented using the intrinsic possibilities of this technical medium. In experimental practice, however, these two steps do not develop divorced from one another. Rather, they influence each other reciprocally and build each other up, as it were. Thus, the medium of the phenomenon and the medium of its fixation must be interrelated, but in their relatedness preserve their own characteristics and their respective potentials. Indeed, it is a key trait of the infrascopic core area of experimentation that the fleeting and as such often also invisible traces produced within the experimental setup are transformed into a permanent and visible trace of data. This is a precondition, in turn, for an analysis of these traces.

So, we are not dealing here with technical reproducibility as a repetition of the same natural phenomenon, a repetition that can be arbitrarily called up again and again. A good experimental setup does achieve this, but in practice it is always about nuances in this calling, which is the only way something new can be learned about the phenomenon. But this is the rather trivial aspect of technical reproducibility. By contrast, the non-trivial aspect consists in making an event, having once taken place, available in a technical medium that conveys a manipulable and reproducible form to it and thus enables the event to become an epistemic event to begin with in that medium. This also means that as a rule, epistemic events in the very first place become manifest in the medium of such a technical transposition, in the space of technical bricolage, through the doubling of the epistemic thing in its technically reified form. The possibilities connected with this doubling depend decisively on the medium in which it takes place. A few of these media-specific possibilities of film will now be discussed briefly.

The film material that the image part of Bulletin n° 09 presents stems from the former Kaiser Wilhelm Institute for Fluid Dynamics, founded in 1925 in Göttingen under its director Ludwig Prandtl. The Bulletin concentrates on flow patterns, particularly on flow figures, arising due to obstacles, in the form of more or less regular turbulences and swirls. Thus, we are dealing here with two aspects of flows that in their filmic fixation are dependent on two different technical procedures: On the one hand, it is about the representation of motion sequences with their change differentials, and on the other about the representation of more or less metastable flow patterns or flow figures in a state of dynamic equilibrium.

First, let us briefly turn to the representation of motion sequences. Here, film as a technical medium offers basically two possibilities of visualization, which can briefly be summed up as follows: That which is too slow to be seen is technically accelerated; and that which is too fast to be seen is technically decelerated. The procedures are known as fast motion and slow motion. Filmic fast motion played a decisive role at the beginning of the twentieth century for, say, the visualization of plant movements that are too slow to be seen with the naked eye. Slow motion, on the other hand, is used to capture movements that are so fast they cannot be seen with the naked eye. Many of the serial images shown in the Bulletin deal with such phenomena. Here, the series stands in for the movement – it is, paradoxically, its 'frozen' form. The extreme form of slow motion is movement that is reduced to a single image and thus completely immobilized: the still picture. But irregular phenomena of turbulence resist immobilization—their representation requires moving pictures or whole series of stills.

This leads over to flow figures. Flow figures can be described as phenomena that remain constant for at least a certain period of time. In film, they are perceived as standing. Since nothing changes over time, in principle even a snapshot suffices to represent the phenomenon in its totality. But often the dynamic of these phenomena seems to be inscribed in their very form. A textbook example of such a figure is the spiral, which in its flow activity usually appears in forms that approach its logarithmic variant. Many of the images shown in the Bulletin are spirals, with particularly prominent ones on page 228 and 229. Page 255 shows a developing spiral of a logarithmic type in the form of a series of stills. In principle, however, each one of them suffices to represent the whole developmental process; the figure visualizes its own algorithm. While the phenomenon does not stand still here, the proportions in which it changes remain constant. Hence each image finally exposes the dynamic it is part of.

The Melancholy of Repetition

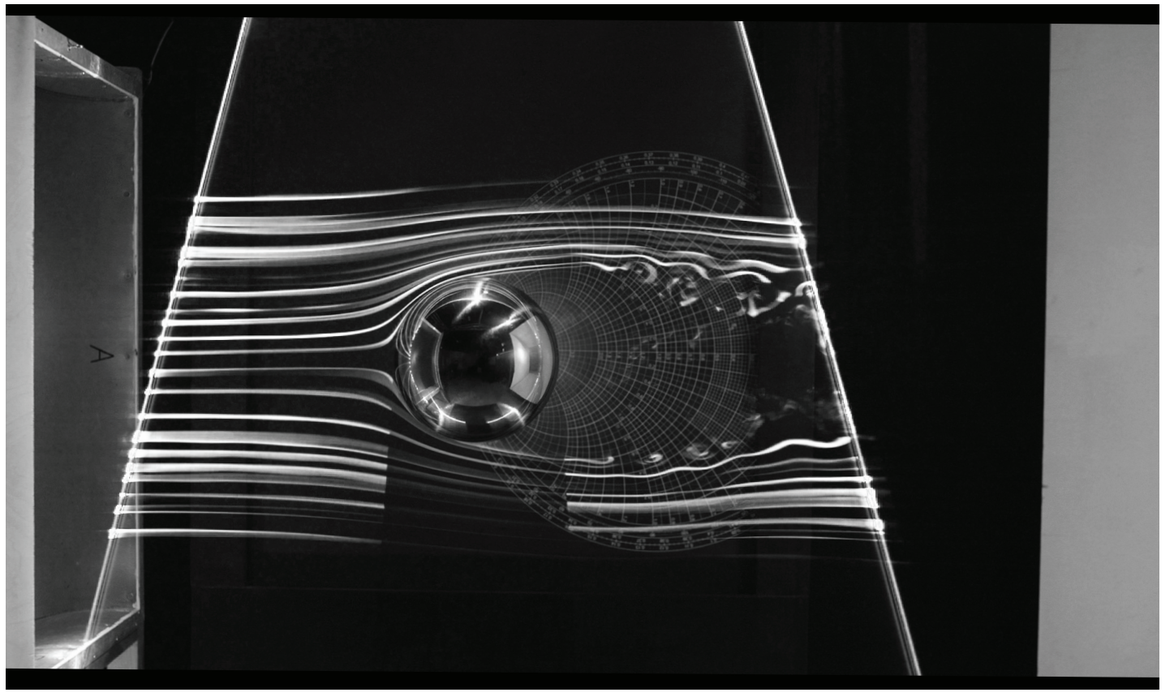
Florian Dombois
(Artist, Zurich)

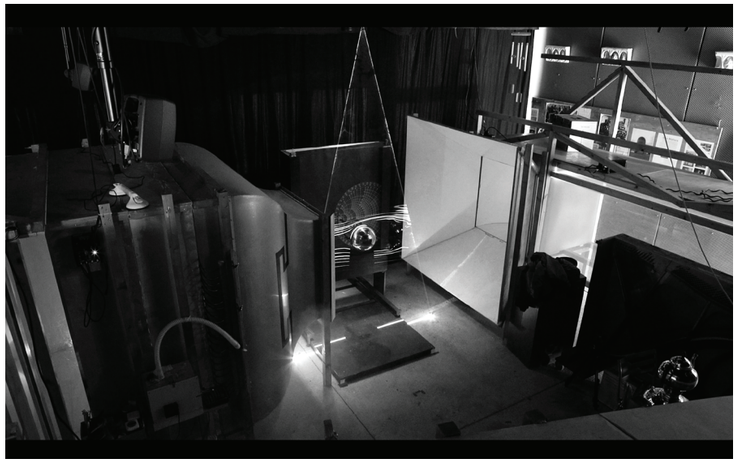
We operate an artistic wind tunnel on the roof of the art school. A Göttingen-type tunnel with an open test section, that is, one that can be entered at any time from the outside. And not only can we intervene ourselves in the laminar air flow, but every other event quickly becomes noticeable: if the wind is blowing outside, it blows away the streaks of smoke in our unprotected laboratory. If a train comes shooting through the nearby tunnel, its pressure wave shifts our technically generated wind. Our facility on the roof stands freely exposed, bare, only lightly covered by gates made from thin sheets of foil and black theater curtains.

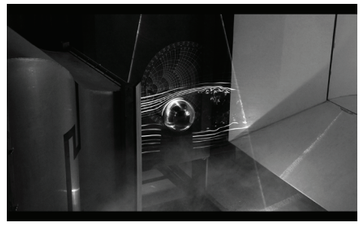
Here, in this place, no day is like another. Here you freeze when it snows and sweat when the sun shines. Here you hear the city and nearby construction sites; here you can see the roofs of buildings and all the way to the distant crests of the Alps. And here, at this place of transformation, we continually light the little coals of shisha pipes in order to evaporate our copal on its embers. Its white smoke is pressed by a computer fan through numerous hoses and blown into the wind of the large fan. There, the smoke forms streaks that we maneuver into the light plane of a laser with side flaps and also, at times, by positioning ourselves suitably relative to the flow of air. And this often doesn't work and we have to repeatedly make adjustments so that the wind—and with it, the smoke—meets the light.

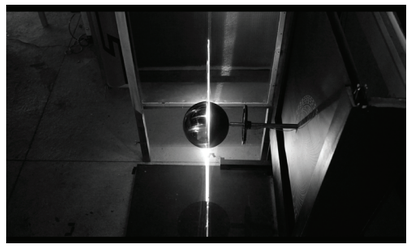
And then: maybe. Then, if it suddenly works, then streaks of white smoke gush forth and we watch breathlessly as they prance through the light plane. Then, it looks very easy for a few minutes, and we are enchanted by the grace of the lines. Time stands still and the white threads of smoke meander in it. Until the smoke extinguishes, or a train comes, or a gust of wind on the roof pushes everything out again.

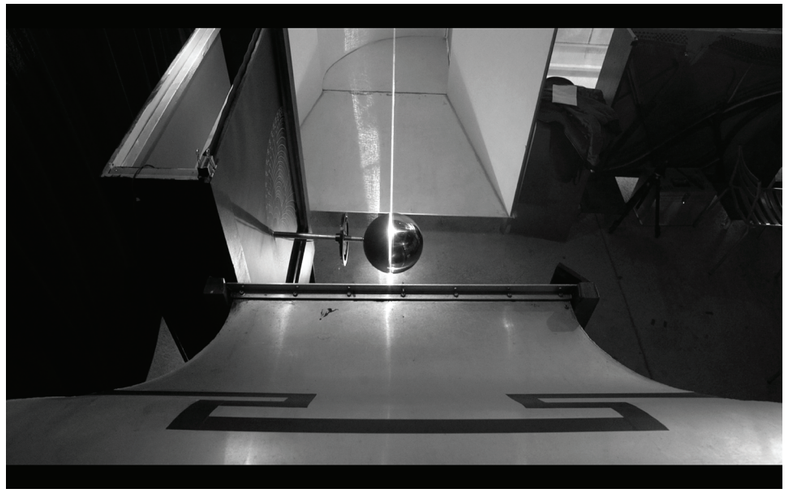
These moments, when the wind comes out of nowhere to show itself to those of us who are standing around, are for me moments in which something is fulfilled that I associate with art. And then we take out our camera and capture perhaps an iota of the reality. And yes, people who were not on the roof with us might also be enchanted by our pictures and films and extol and enjoy their aesthetic. But for me, the moment of art will then be gone; you cannot capture or reproduce it. Not even when you recite it endlessly and with autosuggestion invoke a moment of art and an aura. Yes, the images from the wind tunnel possess an aesthetic surplus; they are too beautiful for science. But is that art? And the melancholy that seizes me is not only due to the repeated viewing of the film loops of windy movement, but even more due to the repetition of the claim that we are now coming to grips with art. You cannot come to grips with it: you cannot confine it; it always shows itself differently, always anew. It only comes when it wants to. And that's why I believe in it.

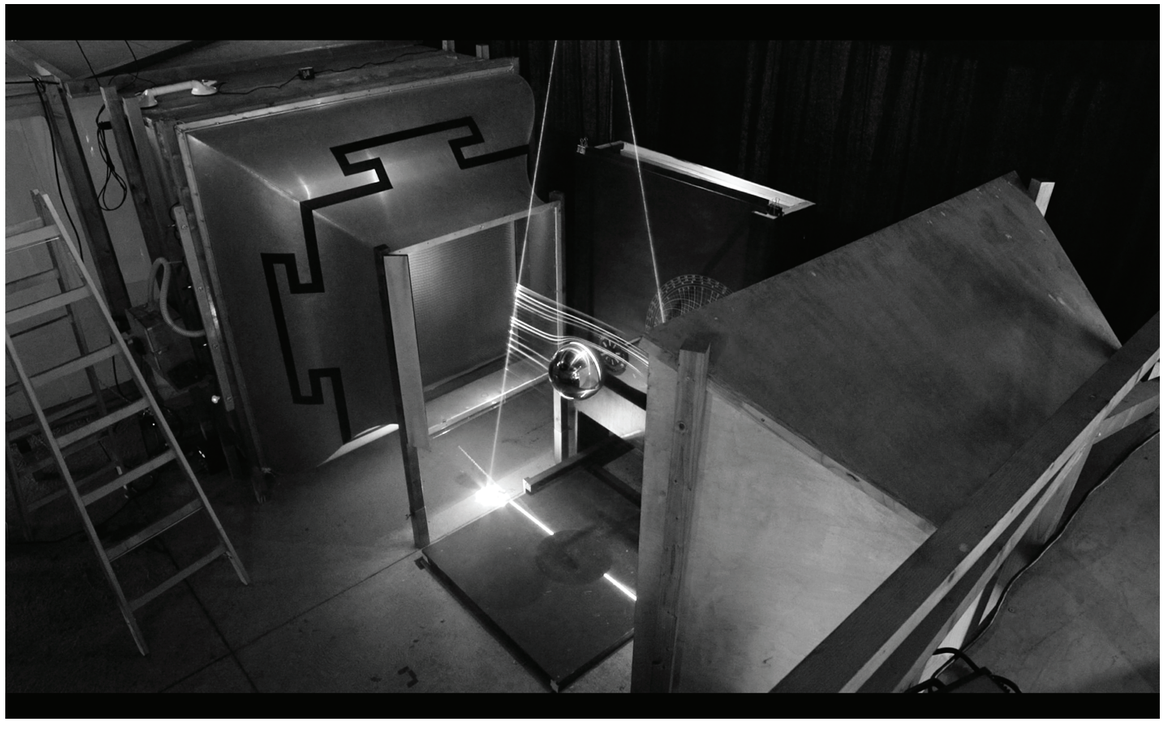


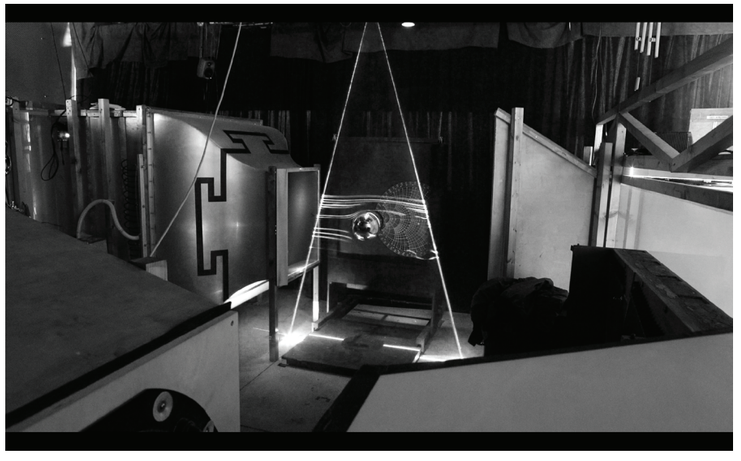












Not a Flip Book

Christoph Hoffmann
(Science historian, Lucerne)

When I let the little image part run through my fingers, nothing is set in motion. There are no flowing forms, no “Hinüber” (“across,” as Max Wertheimer essentially characterized the motion effect in 1912). No matter whether I leaf through it slowly or quickly, from the front or the back, there is a black-and-white, gray tangle; not unformed, yet disconnected. As I go through the image part of Bulletin n° 09, the same question arises in concentrated form that is raised by the image material printed in it: How should these photographs be viewed, how were these photographs viewed at the Kaiser Wilhelm Institute for Fluid Dynamics way back then?

The question, formulated in this way, suggests there is a *right* approach. But this is doubtful, not only because first one would have to clarify who decides how *right* should be defined: the producers or the viewers? It is doubtful that there is a right approach above all because the image material itself suggests there are several. It may have been called film or filmstrip in the institute, but playing and projecting the material again at the original recording speed is only one possibility of using it, and presumably the possibility that was initially of least interest. It is much more likely that the filmstrips were viewed slowed down, perhaps only on a small screen, like at an editing table. I imagine the strips were run forward and backward, that the scientists went through individual moments of the recorded flow activity again and again. I imagine they copied individual sequences from different time points of an experiment, or sequences from different experiments, on paper in order to study them juxtaposed.

The basic operation with scientific image material is that of comparison. For scientists, viewing an image means setting it against another image. It means noticing differences, and also measuring it if possible. Movement, “Hinüber,” is in this context only one quality among others. Movement provides clues that have to be pursued by slowing down or stopping the sequence, or by confronting it with other sequences. Or movement itself becomes the problem: When does it arise? Under what circumstances? What forms does it take on? When does it disappear? In this case, too, the image flow would have been manipulated via the playing speed, from strong acceleration to standstill. Only the audience is permitted to simply watch during the lecture, and at the same time hear what it is supposed to see. “Pretty pictures” (Michael Lynch & Samuel Y. Edgerton Jr.): without novelty value for the presenter, but carefully chosen and mounted, embedded in the speech, convincing under these circumstances.

How these images should be viewed ultimately depends on who gets to see them in which situation. But I shouldn’t have asked myself this question. The little supplement contains a sheet of paper with some information and a different question: “What happens to an experiment when it is captured on camera and then reproduced, evaluated and distributed as a film?” Two answers occur to me. First, the experiment will be set up with its recording in mind from the start and the whole planning will be calculated with reproducibility in mind. This is already apparent from the ballistic photographic shots by Ernst Mach, Peter Salcher and Ludwig Mach in the 1880s and 1890s. And second, a distinct kind of experimental usage will take shape when dealing with the image material produced. I just wrote down some conjectures on this subject. I thought not least of the ultra-high-speed films that were made after 1900 at the Ballistics Laboratory of the Technical University Charlottenburg. Peter Berz told their story in *08/15*: A few hundred individual images were recorded in a fraction of a second in order to dissect shots and weapon-related processes in as much detail as possible. They were turned into films primarily when screened publically, for example for “the flight-pornographic amusement of the highest commanders-in-chief.”

On Following in the Image

Inge Hinterwaldner
(Art historian, Karlsruhe)

Where experimental setups are prepared in order to eagerly observe how the interaction between all the components will take shape, when it comes to the imagery of experiments recorded as films the question arises: How can one manage to impart something akin to contingency in filmic documents? The usual means of conveying it visually by expressing indeterminacy in the form of blurriness, or *sfumato*, cannot be deployed in the case of flow dynamics, which are represented visually precisely using very tiny elements. Abstraction is the means of choice for Friedrich Ahlborn, who in his schematic drawings sets down his observations steeped in extensive experience, sometimes with the help of diverse photographic techniques. Another possibility would be a kind of relativization by means of seriality—stringing together different results of the same experimental setup. The differences between the images would open up a view of the scope of variations. This kind of summation would accommodate the filmic *dispositif*, as repeated recordings from the same angle under uniform conditions are feasible in principle.

However, an important basic attitude has not been considered yet: If an open end is an essential component of a scientific experiment, then the attitude of ‘following’ the materials is adequate. The anthropologist Tim Ingold develops this aspect in his ecology of materials.[37] He refers, among others, to Gilles Deleuze and Félix Guattari, who write in *A Thousand Plateaus*: “A distinction must be made between two types of science, or scientific procedures: one consists in ‘reproducing,’ the other in ‘following.’”[38]

Ingold views these as two fundamentally different approaches. ‘Reproduction’ implies the permanence of a fixed external viewpoint, while ‘following’ traces singularities in the flow of material. The latter approach is often implemented approximately at technology museums and is called for by Ionat Zurr in the context of a posthumanist aesthetics.[39] Presentation is preferable to representation, she says, when it’s about the surprisability of the material. At this juncture, I’d like to point out that even when dealing with presentation forms, it is possible to differentiate; so in the following, three variants will be compared with each other. We can thus differentiate between an experiment with an open end, a purged and already well-tested museum version, and a filmic reproduction of an experiment, based on several parameters.

First, differences can be found regarding the degree of transparency of the processes of negotiating an experimental setup under technical, social, and disciplinary aspects. While in the first case this is fully developed, in the mode of presentation suitable for the general public a lot of infrastructure (including laboratory life) is eclipsed, and the black-boxing seems to be pushed even further forward in the filmic document because details of images are selected. Here, one would have to first invest some effort to again find a link to “science in action” (Bruno Latour).

Second, a further parameter of differentiation is selection, i.e. the selectability of that which is put on view. In an experiment, one can generally assume that by means of adaptations in the course of the iterative investigation of the phenomena with the help of diverse instruments all possible approaches for useful access are taken or explored. In a hands-on museum exhibit, a robust selection is made and the people interacting with the exhibit have hardly any possibilities of intervention other than the ones provided. But the course selected is anyhow always self-similar and imparts a connection to one’s own triggering. The film shows a historical event from a specified perspective. If interventions are permitted at all, they are related specifically to the medium of film, for example viewing in a loop or in slow motion.

Third, there is another parameter that differentiates the senses appealed to in each case: smell, air movement, moisture or deafening noise can be experienced in a real experiment. In exhibition pieces, glass panes often filter the tactile and acoustic. In film, the visual is given further emphasis —and possibly also contrast vision, if the recordings are in black and white.

One could perhaps take the aspect of risk as a peg to return to the question of ‘following in images.’ Imponderables and problems—called singularities by Deleuze and Guattari—often arise in experiments. If we choose the approach of following, they enable us to repeatedly adjust the experimental setup and bring movement into the dance around the phenomenon. ‘Following’ in the reproduced image—and that would mean softening up the strict separation between the two types of science—would presuppose that risk, surprise and maneuverability would have to be retrievable in the image. In a scientific context, a single image is not usually meaningful, but rather the totality of the performances presented, the artifacts produced, or the observations made. Ludwig Prandtl’s polished films have a different kind of conciseness.

Granular Images—Fluid References

Hannes Rickli
(Artist, Zurich)

One of the world’s most famous paintings is Vincent Van Gogh’s *Starry Night*, which the artist painted shortly before his death in the Provence region of southern France in 1889. It shows celestial bodies above the city of Saint-Rémy-de-Provence. With iridescent currents swirling around them, the stars seem to gain luminous power. The paint was applied to the coarse canvas with fast, short brushstrokes. The celestial phenomena that motivated Van Gogh to represent these dynamic currents can be guessed at only indirectly. Yet it is remarkable that the directed granular structure in which the turbulences in the sky are painted bears a striking resemblance to the stills that were recently produced from films of the Kaiser Wilhelm Institute for Fluid Dynamics in Göttingen from the 1920s (cf. image part).

Since the 1870s, photographic images had circulated that showed movement sequences of animals, people and objects serially, and toward the end of the century also increasingly images that depicted the mechanisms of inanimate matter in order to study them scientifically. The technical visualizations aroused the interest of painters, and one can assume that Van Gogh was familiar with them. However, experimental flow visualizations in water channels and wind tunnels were only realized systematically starting at the beginning of the twentieth century and seem to build on the principle of the representation of moving matter that Van Gogh developed in psychopathic surges: The interspersing of light-reflecting tiny particles makes their changes of direction visible in their spatio-temporal development and thus also visualizes the energy of the matter. Although experimental flow visualization seen from the vantage point of the history of science may not have developed this way—engineers becoming inspired by Van Gogh’s techniques to apply similar visualization strategies—from an aesthetic point of view the (actual and imagined) movements of the materials used to represent dynamic motifs are central: sand, powder, smoke, gas, steam, pigment, threads, and pixels are matter in flow and at the same time capable of making the ephemeral visible as such.

While painters working at the end of the nineteenth century arranged their materials in order to express retinal sensations, engineers and scientists active at the beginning of the twentieth century organized the granules based on efficiency: They sought to optimize shipping and aviation as well as combustion engines for upcoming global wars. Whether today we see the work of an artist or the experimental traces of an industrial program, the visual appearance of the images is equally fascinating. Mesmerized, the eye follows the particles and composes them into movements. In the age of digital mainframe computers, algorithms can be used to capture, for example with particle image velocimetry, both Ludwig Prandtl’s flow visualization film made in Göttingen and the effects of *Starry Night* in mathematical models and prove their respective plausibility in subsequent simulations.[40]

Contemplatively viewing the chaotic-ordered activity of turbulences is an aesthetic pleasure that gives one food for thought about the existence of a world outside of the self and simultaneously about the dynamics of states in one’s own inner world. Any new screening of Prandtl’s films, or only the printing of different stills from his films, fulfills this promise, as does Van Gogh’s painting. Some home objects do this as well. Glassed in and illuminated from the back, they project in the form of moving colored clouds the play of light on the wall after work, leaving us to muse on the laws it obeys. So-called screen savers had a quite technical background not too long ago. When they were on, one could see how the screens of a PC or laptop protected against pixel burn-in with arbitrarily generated color streaks.

When traces of experiments are stored in archives as films, they become unproductive for film studies, according to a thesis of the film historian Yvonne Zimmermann.[41] As a product of research they merely represent a transition stage from which engineers measure the phenomena recorded in later steps and gradually translate them into mathematical equations. The actual filmic aspect, the local and particular circumstances of the experimental production of flows, as well as the temporal, spatial, and social conditions lose their references when transferred to the archive and cannot be reconstructed from the material itself. They lose their context.

Once their functional context is discarded, as decontextualized artifacts they can take on new meanings in art.[42] With regard to Walter Benjamin’s artwork essay, the question arises as to what in Prandtl’s archive films is reproduced and transformed. The materiality of the event in the experiment? The visual enjoyment? The relevance of fluid dynamics in the age of sophisticated high-tech simulations as one of the remaining math and physics problems of the millennium? The possibility of reflecting on historical contexts of a society steeped in science based on the distributed film material? The divergence of interpretation possibilities also has to do with the migration of forms such as granules, brushstrokes, colored clouds, threads, and pixels

from art to science and back and hence with the aesthetics of various kinds of images that interconnect and, depending on the perspective, change the direction of their meaning.

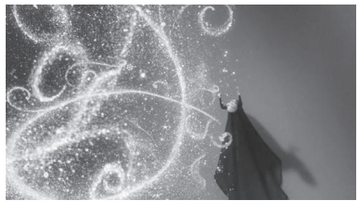
Toward a History of Particulate Media

Oliver Gaycken
(Cinema and media historian, College Park)

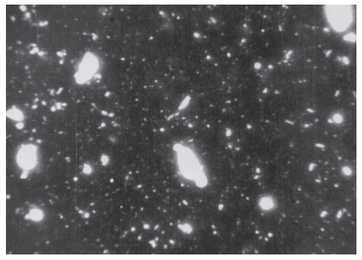
The revelatory images reproduced in the image part of Bulletin n° 09 allow illuminated particles to make the invisible power of flowing water apparent. These images also mobilize a swarm of associations. A primary layer is that of precursors in the field of aero- and hydrodynamics, chronophotographic and cinematographic records created by Ernst Mach, Etienne-Jules Marey, and Henri Bénard and Camille Dauzère (who made a series of eight films about fluid dynamics for Gaumont in 1913–1914).

A wider circle of moving-image experiences that record or create similarly extraordinary movement also can be drawn, and these remarks will sketch the contours of a family group of images that eddy across media history, tracing a history of technology's engagements with contingency. The first analogue comes from the domain of effects animation, which reached its zenith in the era of classical animation at the Walt Disney Company with *Bambi* (David Hand, 1942).

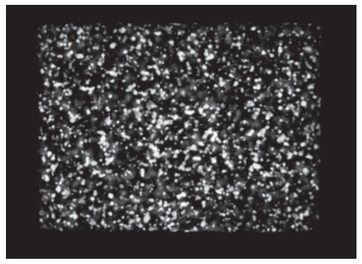
This tradition has been remediated for the present with the emergence of computer-generated images of complex phenomena, such as the wide variety of snow and ice effects in Disney's *Frozen* (Chris Buck and Jennifer Lee, 2013).



A second analogue comes from dark-field microscopy (*Amoeba*, Jean Comandon, 1910): "I no longer know if I'm looking with my naked eye at a starry sky or at a drop of water through a microscope." (Blaise Cendrars, *Profond aujourd'hui*, 1917)



A final example can be drawn from the tradition of experimental filmmaking: In *Apparent Motion* (Paul Sharits, 1975), the phenomenology of the film's grain becomes the object of contemplation (thanks to Andrew Lampert for mentioning this film to me).



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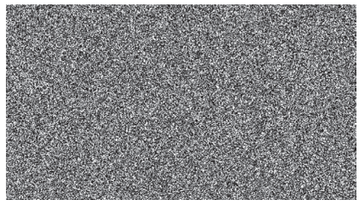

Seduced by Form or Flow? Etienne-Jules Marey's Experiments on Airflow Dynamics

Janina Wellmann
(Science historian, Lüneburg)

In his final years, Marey dedicated his research to the movement of fluids. In many respects, this research raises more questions than it provides answers. Between 1899 and 1901, Marey constructed wind tunnels—among the first of their kind—to study the dynamics of airflow.[43] Several publications and communications to the Paris *Académie des Sciences* document the experimental setup and the optical devices and techniques he tested to make what he named chronophotographs.[44] In contrast to his better-known chronophotography of human and animal locomotion, which shows movement trajectories by way of multiple exposure of a single plate, these images are instantaneous photographs of air flowing around geometrical obstacles.

The prevailing historiography is clear about these images: aesthetically a major achievement because of their striking visual poetics, they failed scientifically as Marey's purpose was measurement (not beauty). Despite attempts to measure the velocity of airflow in later versions of the wind tunnel, they did not provide quantification. Also, Marey does not give a theoretical background or context for these studies. On the one hand, the research on dynamic airflow follows from his aerodynamic interests in aviation; on the other, it returns to his investigations of blood, respiration and temperature, which he pursued at the outset of his career in the 1850s.[45] Hence, epistemologically, the status of his investigation remains quite enigmatic in terms of both his own research trajectory and the physics of fluid dynamics.

Scholars have been particularly intrigued by Marey's own characterization of his pictures: why did Marey, who was both creative and skilled in building experimental and optical devices, use instantaneous photographs, and why, to add to this puzzle, did he refer to them as chronophotographs? The answer implicit in the question is that chronophotography, not instantaneous photography, would have been the appropriate medium to capture airflow dynamics. But chronophotography, perhaps even to Marey's own surprise, turned out to be a medium incompatible with air, the object of study.[46]

In the following I want to dwell on the opposite thought: what if instantaneous photographs of airflow dynamics turned out to be exactly right to attain Marey's goals? The argument I want to put forward in favor of this idea is the methodology of the experiment, more precisely the requirement of its reproducibility to validate it.

Throughout his life, Marey constantly used and improved the graphical method and chronophotography with the ultimate scientific goal of measuring the forces at work in moving bodies, be they organic or physical. His experimental setups and visual depictions were tools to gain access to otherwise invisible physical forces. The kind of measurement that diagrams or chronophotographs enable is the quantification of displacements and trajectories of luminous markers against a dark background, or of the distances traveled between concrete points on a curve etc.—hence the argument that chronophotography is not suited to capture or trace a substance as amorphous and elusive as air. Moreover, it was not the empirical-pictorial approach taken by Marey and others but mathematics that ultimately drove the subsequent advancement of the science of fluid dynamics.[47] However, I would argue that the measurement, which Marey derived from his instantaneous photographs, was not to be found *in* the picture but *between* pictures.

At the end of his series of studies, Marey introduced a ruler and timer to his wind-tunnel experiments to measure the velocity of air. The pictures in this series are taken "à la lueur d'un éclair magnésique, c'est-à-dire en un temps si court que chaque filet de fumée apparaît comme s'il était immobile."[48] Frozen in an instant, the air takes the shape of an object, whose form and dimension can be varied "à l'infini" by changing "les corps plongés dans le courant d'air."[49] Put differently, the movement of air is depicted here, in the words of Aby Warburg, as *bewegtes Beiwerk* [moving accessories]: movement is visualized as being added to the object, in this case obstacle, achieving—like the fluttering garments and blowing hair which Botticelli added to the naked Venus—"eine gesteigerte äussere Bewegung."[50] With the air figuring as an 'animated object,' Marey is able not only to infinitely vary its shapes and thereby study the behavior of dynamic airflow when it comes into contact with a fixed object. He is also, inversely, able to ensure the identical reproduction of the object "si l'on repète, deux fois de suite une expérience, en conservant les mêmes conditions." It is precisely the reproducibility of an identical shape, of images "identiques et superposables entres elles," that serves as "une preuve de la précision de la méthode."[51] Marey could verify the validity of his measurements by comparing the animated objects created in the instantaneous photographs. Hence his method of choice was a classical comparison between pictures. Combining measurement and pictorial depiction, those photographs not only addressed the observer aesthetically and guaranteed the validity of the experiment methodologically. Marey confidently added that this method also provided "la solution expérimentale de divers problèmes relatifs aux appareils propulseurs dans les fluides, aux questions de ventilation etc."[52]

In a letter to his colleague Georges Demenÿ in 1886, Marey wrote that making air visible "seduced" him to do this research.[53] When he came to the end of his series of investigations in 1901, however, seduction had to turn into proof. The reproducibility of the experiments was crucial not only to verify Marey's pictorial approach but also to assert his scientific legacy.

Interview

With Jimena Canales
(Science historian,
Boston/Urbana-Champaign)

What does film do to an experiment or experiments in general?

We usually think of film as a recording instrument, one that passively creates a copy of an event that can then be archived, reproduced and watched at leisure. What we forget is how film completely changes the entire experimental system. It changes the 'politics' of the experiment and at the same time that it reflects 'political' changes.

What do you mean by politics?

I use the word political in a broad, not narrowly defined sense that includes subtle changes in power structures and the formation of subjectivities. These are the changes that I have tried to highlight in my work on the history of early film and pre-cinematography. Consider, for example, the case of the transit of Venus observations made in 1874 and in 1882. They motivated the construction of some of the earliest pre-cinematographic devices because scientists found themselves disagreeing about the precise timing of an event in space. In this particular case, they disagreed about the moment when Venus appeared to make contact with the Sun. Instead of continuing to disagree, instead of continuing to compete and fight with their colleagues in nearly every country in Europe about when the contact occurred, scientists built a new device to record it. That "photographic revolver," as this pre-cinematographic camera was then called, was designed to shift the burden of proof away from individual observers caught in the moment to a record that could be analyzed at leisure by many observers at the time. If disagreements still persisted in the reading of this record, it could then be measured with a micrometer. The micrometer itself, as well as the cinematographic camera, is also 'political' in the sense I just described. In fact, any measurement technique is 'political' in this sense. If we look at the history of measurement and recording instruments, we quickly come to the conclusion that nothing is more imprecise than precision itself.

You refer to the film camera as a measurement technique. In your book A Tenth of a Second *you tell the story of how the camera often failed scientists trying to extract quantitative figures from celluloid. But if the film camera often failed as a measuring device, why has it nonetheless been so successful in the exact sciences?*

Yes, as is often the case with new inventions, the "photographic revolver" did not fulfill the wishes of its creators. Even though scientists used a micrometer to measure the glass plates taken during the first transit of Venus, they were unable to convince the larger international astronomy community of the value of those measurements. So for the next transit of 1882 they decided to drop cinematography and photography altogether from the official collaborative enterprise. What is most interesting is that at the same time that early cinematographic techniques failed as precision instruments, they started to open up an entirely new aspect of the world to new forms of observation, switching spectatorship practices that had originated in laboratories to theaters. I am very interested in this bifurcation—the moment in history when precision and spectacle parted ways—because of what it says about larger social and political

transformations of that time and the notion of truth.

Walter Benjamin called

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shocking and potentially deadly—like "dynamite." The desire that drives the creation of permanent records of the evanes- have much in com- with the desire to erve a mummy, build cophagus, peel a n mask from the face e recently departed, serve a body part in of formaldehyde, ore commonly, keep ry. Death and birth the extremes of ics. To change the ion between the two change the world e most dramatic way ible.

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Umlenkung ist durch Zentrifugalwirkung außen höherer Druck als innen. Es ergibt sich also Druckanstieg und Ablösung auf der Außenseite am Beginn des Krümmers und auf der Innenseite am Ende des Krümmers. In dem Spiralgehäuse mit Abfluß nach unten stellt sich im Verlauf des Vorganges eine Strömung mit Geschwindigkeiten umgekehrt proportional zum Abstand vom Wirbelzentrum ein. Bei den Strömungen durch die Kästen ergibt sich, wenn der eintretende Strahl nicht bis zum Grunde reicht, und so die Räume zu beiden Seiten des Strahls unten herum in Verbindung stehen, im wesentlichen ein gerader Strahl; reicht der Strahl jedoch bis zum Grunde des Kastens, so sind die beiden Toträume von einander abgesperrt. Es stellt sich jetzt ein Druckunterschied ein, durch den der Strahl unmittelbar auf die Ausflußöffnung zufließt. Bei den Verzweigungsstücken ist die Wirkung dieser „Absperrung" ebenfalls zu beobachten. Wenn für den Abfluß zwei Wege gleichzeitig offen sind, dann werden diese Kanäle im Dauerzustand nur etwa halb von der Strömung gefüllt, da statt der Verzögerung der Strömung eine Ablösung eintritt. Bei den T-Stücken ergibt sich bei Ablenkung nach der Seite auch eine Ablösung der Strömung an der geraden Wand (deren Möglichkeit gelegentlich bestritten worden war).

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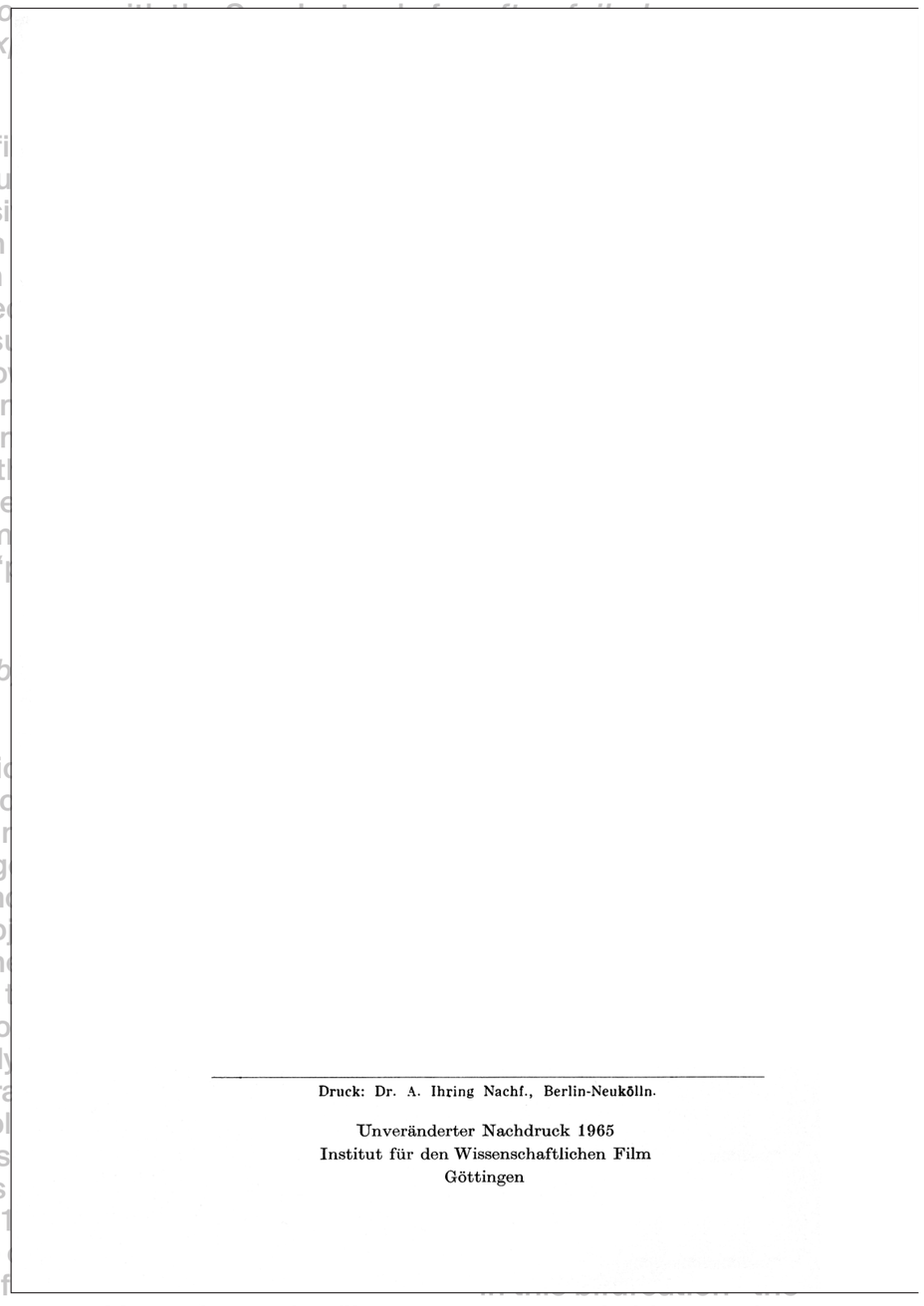

Druck: Dr. A. Ihring Nachf., Berlin-Neukölln.

Unveränderter Nachdruck 1965
Institut für den Wissenschaftlichen Film
Göttingen

Walter Benjamin called one of these new aspects of the world that the film camera opens up the "optical unconscious." What do you think is the optical unconscious in science?

If we do not think carefully about photography and film, we may just say that it records reality. But when we think about it more and look at its history, we can start to see how it is also an instrument of discovery, one that challenges what we consider to be real. Its potential for discovery, however, is not entirely open-ended. Photography and film have uncovered things that were not known to exist—yet, paradoxically, were "always already there" as part of nature. It is this gap between the "existing" and the "not yet existing" that Benjamin's "optical unconscious" points at. When photography was first invented, the images produced by the camera shocked viewers because they could recognize them as being similar to what they knew before in some respects (perspectival, sketch-like, etc.), but dissimilar in others (monstrous detail, moving things disappearing, etc.). This shock represented the clash between the 'conscious' optics of the machine (which could be understood rationally in term of physical optics, chemistry, etc.) and the 'unconscious' ones (which were described as uncanny, ghostly, and mysterious). It is daunting for scholars and historians to try to study the latter. Benjamin tried, and for this reason made ritual, myth, magic and spirituality central to his analysis. After studying the development of science and technology across the centuries, with a focus on visual technologies, I have become convinced—with Benjamin—that those 'unconscious' aspects are very much in the driver's seat.

What does it mean for non-repeatable and fleeting phenomena in particular if they can be captured on film? Or, in other words: What are the ghosts (and politics) of the flow that the camera might reveal?

For Benjamin, the effects of the "optical unconscious" clearly appeared when the camera was used to capture short moments of time beyond the threshold of our perceptual abilities. Disclosing it could be liberating, but it was also shocking and potentially deadly—like "dynamite." The desire that drives the creation of permanent records of the evanescent have much in common with the desire to preserve a mummy, build a sarcophagus, peel a death mask from the face of the recently departed, conserve a body part in a jar of formaldehyde, or more commonly, keep a diary. Death and birth lie at the extremes of politics. To change the relation between the two is to change the world in the most dramatic way possible.

1 Film and cinema created new social realms, extended human perception, produced diverse local and global film industries and not least of all were used in science and for propaganda purposes. Flow research and aerodynamics made locomotion at high speeds possible. In this way they revolutionized travelling, thus not only transforming people's everyday lives, but also determining global trade, the development of diverse war technologies, and the space race.
2 Cf. in particular the research of Georges Didi-Huberman/Laurent Mannoni, Daniela Hahn, Inge Hinterwaldner, and Christoph Hoffmann.
3 The expression "cinematographic turn" was coined by Jimena Canales (cf. Canales, Jimena, 2002, "Photogenic Venus. The 'Cinematographic Turn' and Its Alternatives in Nineteenth-century France", in *Isis* 93(4), 585–613). On film as an instrument of research cf. in particular the writings of Canales, Scott Curtis, Oliver Gaycken, Hannah Landecker, and Janina Wellmann.
4 Cf. Schulze, Mario, and Sarine Waltenspül, 2019, "From Images of Lines to Images of Particles. The Role of the Film Camera in Flow Visualization", in *Yearbook of Moving Image Studies* 4, 166–191.
5 Cf. in particular Hediger, Vinzenz (ed.), 2005, *Montage AV* 14(2); Rickli, Hannes (ed.), 2011, *Videogramme. Die Bildwelten biologischer Experimentalsysteme als Kunst- und Theorieobjekt*. Zurich: Scheidegger & Spiess.
6 Benjamin, Walter, 1991 [1936], "Das Kunstwerk im Zeitalter seiner technischen Reproduzierbarkeit" (dritte Fassung), in id., *Gesammelte Schriften*, vol. I, ed. by Rolf Tiedemann, and Hermann Schweppenhäuser. Frankfurt am Main: Suhrkamp, 471–508, 499, transl. by eds.
7 Ibid., 477, transl. and brackets by eds.
8 Cartwright, Lisa, 2015, "Visual Science Studies. Always Already Materialist", in Annamaria Carusi, Aud Sissel Hoel, Timothy Webmoor, and Steve Woolgar (eds.), *Visualization in the Age of Computerization*. New York/London: Routledge, 243–268, 251.
9 Fidler, Fiona, and John Wilcox, 2018, "Reproducibility of Scientific Results", in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy*, https://plato.stanford.edu/archives/win2018/entries/scientific-reproducibility/, (consulted May 2, 2019).
10 An overview of the use of the terms and possible meanings can be found in Fidler/Wilcox 2018.
11 Collins, Harry, 1992, *Changing Order. Replication and Induction in Scientific Practice*. Chicago/London: University of Chicago Press, 18–19.
12 Cf. Wise, Norton, 1995, "Introduction", in id. (ed.), *The Values of Precision*. Princeton NJ: Princeton University Press, 3–13.
13 Cf. Schulze/Waltenspül 2019.
14 Cf. Willert, Christian, and Jürgen Kompenhans, 2010, "PIV Analysis of Ludwig Prandtl's Historic Flow Visualization Films", 63rd Annual APS-DFD Meeting, Long Beach CA, https://arxiv.org/abs/1010.3149, (consulted May 2, 2019).
15 Benjamin 1991, 477, transl. by eds.
16 Cf. *Schul- und Volkskino. Der Film und das stehende Bild im Dienste der Belehrung, Aufklärung und Werbung* 1, 1921, trans. by eds.
17 Cf. Tolle, Wolfgang, 1961, *Reichsanstalt für Film und Bild in Wissenschaft und Unterricht*, Berlin: self-published.
18 Doane, Mary Ann, 2002, *The Emergence of Cinematic Time. Modernity, Contingency, the Archive*. Cambridge MA/London: Harvard University Press, 20; cf. Wellmann, Janina, 2011, "Science and Cinema", in *Science in Context* 24(3), 311–328, 324.
19 Benjamin 1991, 506, transl. by eds.
20 Gotthard Wolf to Ludwig Prandtl, June 7, 1951 (AMPG III 61 739), transl. by eds.
21 Collins 1992, 19.
22 Florian Dombois and I jointly conceived the research project *Luftbilder/Lichtbilder* in 2016. In the context of this project, he and Christoph Oeschger create artistic works and Mario Schulze and I write scientific texts. In his works and his research, Florian Dombois has long dealt with the suspension of epistemic hierarchies of language and other media.
23 Galison, Peter, 2015, "Visual STS", in: Carusi, *Visualization*, 197–225, 198.
24 Ibid., 199.
25 Cf. Souriau, Etienne, 1951, "La structure de l'univers filmique et le vocabulaire de la filmologie", in *Revue internationale de Filmologie* 7–8(II), 231–240.
26 Ibid.
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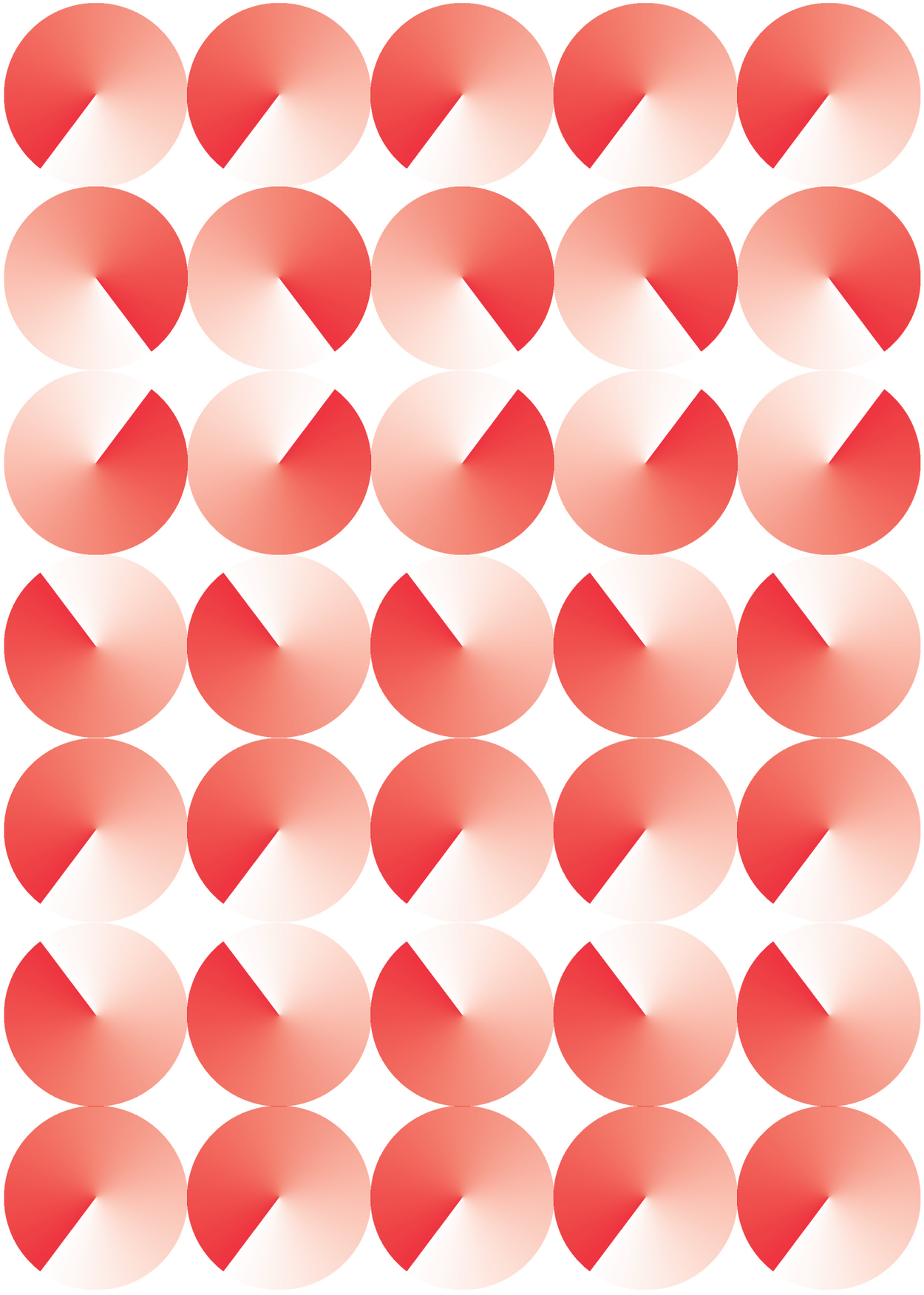
45 On Marey's research on airflow dynamics cf. Braun, Marta, 1992, *Picturing Time. The work of Etienne-Jules Marey (1830–1904)*. Chicago/London: University of Chicago Press; Hahn, Daniela, 2009, "Tourbillons et turbulences. Zu einer Ästhetik des Experiments in Etienne-Jules Mareys *Machines à fumées*", in *ilinx* 1(1), 43–69; Hinterwaldner, Inge, 2013, "Parallel lines as tools for making turbulence visible", in *Representations* 124(1), 1–42; Hoffmann, Christoph, 2013, "Superpositions: Ludwig Mach and Étienne-Jules Marey's studies in streamline photography", in *Studies in History and Philosophy of Science* 44(1), 1–11; Noguès, Pierre, 1933, *Recherches expérimentales de Marey sur le mouvement dans l'air et dans l'eau*. Paris: E. Blondel La Rougery.
46 "The functional logic of the graphical as well as the chronophotographical method each fall short for the wind-tunnel experiments […]." (Hinterwaldner 2013, 15–16), cf. also Hoffmann 2013, Mannoni in Didi-Huberman and Mannoni 2004, esp. 37–41.
47 Cf. Hoffmann 2013, 9.
48 Marey 1902, 133, also Marey 1900. English translation: "in the light of a magnesium flash, i.e. in so short a time that each streak of smoke appeared as if it were immobile." Transl. by eds.
49 Marey 1902, 134, also Marey 1901. English translation: "The bodies immersed into the stream of air." Transl. by eds.
50 Warburg, Aby, 2010, "Sandro Botticellis 'Geburt der Venus' und 'Frühling': Eine Untersuchung über die Vorstellungen von der Antike in der italienischen Frührenaissance", in id., *Werke in einem Band*, ed. by Martin Treml, Sigrid Weigel, Perdita Ludwig, Susanne Hetzer, Herbert Kopp-Oberstebrink, and Christina Oberstebrink. Frankfurt am Main: Suhrkamp, 39. English translation: "a heightened, external movement." Transl. by eds.
51 Marey 1902, 134–135. English translation: "if one repeats the same experiment twice while maintaining identical conditions." It is precisely the reproducibility of an identical shape, of images "that are identical and superposable among each other," that serves as "proof of the precision of the method." Transl. by eds.
52 Marey 1902, 135. English translation: "The experimental solution to diverse problems relating to devices that propel fluids, to questions of ventilation, etc." Transl. by eds.
53 Quoted in Braun 1992, 217.



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018	24.05.2018	iPhone on Ricoh (Take 2)
019	24.05.2018	iPhone on Ricoh (Take 3)
020	24.07.2018	Ricoh on Arriflex
021	24.07.2018	Arriflex 16 SR II (Take 1)
022	24.07.2018	Arriflex 16 SR II (Take 2)
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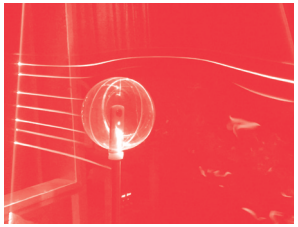
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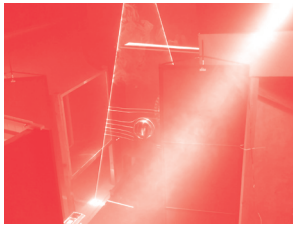
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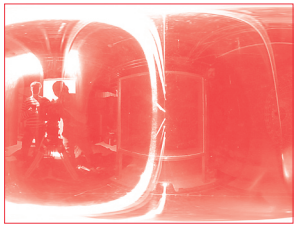
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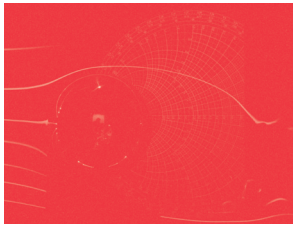
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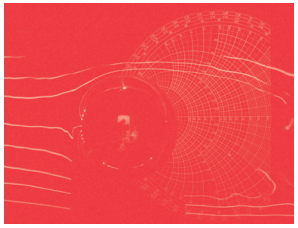
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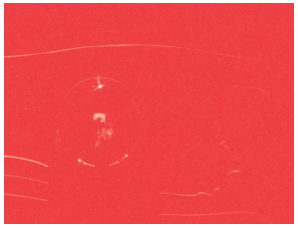
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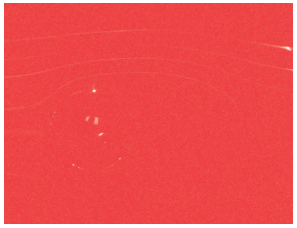
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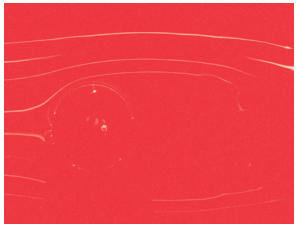
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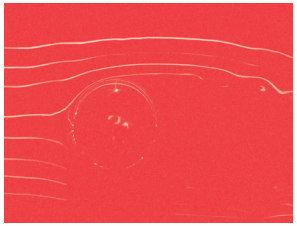
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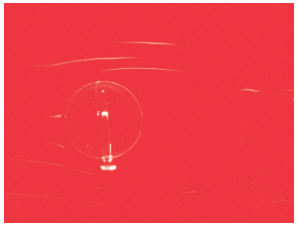
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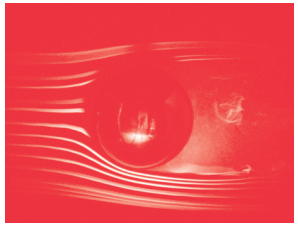
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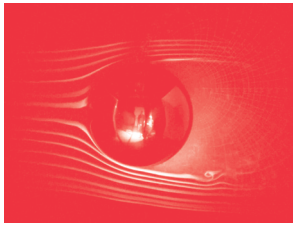
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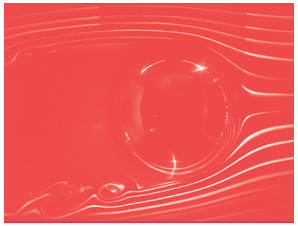
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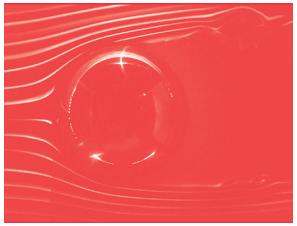
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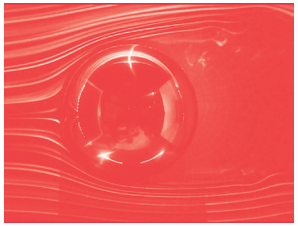
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ISBN 978-3-9524260-8-1

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