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Comments on “A simple model for simulating tornado damage in forests”

(A. P. Holland, A. J. Riordan, and E. C. Franklin, 2006: *JAMC*, **45**(12), 1597-1611)

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1 Introduction

Holland et al. (2006) present a very interesting study on development and evaluation of a simple analytical model of tornado vortex flow and its impact on specified forest configurations. The authors also make reference to earlier work by Johannes Letzmann on near-surface tornado wind fields, dating back to 1923 and reviewed e. g. by Peterson (1992a).

The authors are correct to say that Letzmann did not include information on the physics of tree response (which was unavailable at his time), even though he considered the question if and how twisted tree snapping occurred or how the observed tree damage should be interpreted. However, some other statements by Holland et al. (2006) about Letzmann's work can be misleading. Certainly, the review by Peterson (1992a) alone is not sufficient to fully assess the analytical model developed by Letzmann (1923) in his Ph.D. thesis and later summarized in a journal article (Letzmann, 1925).

It appears as if Holland et al. (2006), based on the limited information they had available on Letzmann's model, reinvented parts of it. Thus it comes as no surprise that some of Holland et al.'s results "are somewhat analogous to the hand-drawn diagrams of Letzmann" (p. 1598) – the underlying model is the same. The fuzzy wording by Holland et al. (2006) may have been influenced by their references: Letzmann (1925) was cited by Hall and Brewer (1959), yet they only referred to "somewhat similar" work by Letzmann, and Peterson (1992a) mentions Letzmann's "hand calculations".

When Holland et al. (2006) refer to Letzmann's work as "experimenting" with various model parameters, and emphasize several times his "hand-drawn" diagrams and "hand calculations", the reader may get the false impression that Letzmann had received his results merely by chance, instead of by the rigorous analytical calculations he performed in his Ph.D. thesis and which also extend the wind field description by Holland et al. (2006). Furthermore, hand calculations and hand-drawn diagrams were state-of-the-art in the 1920s and 30s, just as publishing scientific work in German language was. Nevertheless, the authors must be highly credited for their tying in with Letzmann's research and augmenting it by the modelling of tree response.

The purpose of our comment is to draw attention to the full set of references to Letzmann's work relevant here, and thereby to facilitate ongoing and future research on tornado damage in forests and near-surface tornado wind fields. In Sec. 2, we sketch the historical context under which Letzmann pursued his studies, briefly review his analytical tornado wind field model, and call attention to his guidelines for tornado research and damage surveys, which were approved by the International Meteorological Organisation in 1937. Sec. 3 presents our conclusions.

2 Letzmann's tornado research related to forest damage

Forest damage has traditionally been taken into account when tornadoes or other severe wind events were investigated in Europe, see e. g. Martins (1850), Reye (1872), Wegener (1917), or very recently, the International Conference on Wind Effects on Trees in 2003 (see www.ifh.uni-karlsruhe.de/science/aerodyn/windconf.htm) and Hubrig (2004). Thus, it was quite natural that parts of Letzmann's work on tornadoes were devoted to this field.

2.1 Inspiration by Alfred Wegener

Johannes Letzmann's tornado research was significantly triggered and enhanced by the inspiration he received from Alfred Wegener, nowadays mostly remembered for his work on continental drift. However, Wegener was a dedicated and thoughtful scientist whose research interests covered an immensely broad range in geophysics and meteorology, including thunderstorms and tornadoes.

In his service during World War I, Wegener was injured. After recuperating, he started to pursue a comprehensive monograph on tornadoes and waterspouts in Europe (Wegener, 1917), a classic of tornado research literature. Only recently, Dotzek (2003) was able to update Wegener's estimate of tornado occurrence in Europe.

After Wegener's recovery, he was assigned as a weather advisor on the Eastern Front. With the collapse of the Russian Empire, the Prussian government seized the opportunity to re-establish a presence in the Baltic States, particularly at universities. So Wegener was dispatched to the University at Dorpat (Tartu), Estonia in 1918. Here, Johannes Peter Letzmann (1885-1971) was especially interested in storms and had synthesized a climatology of thunder observations across the area (cf. Peterson, 1995). He soon came under the mentorship of Wegener (Lüdecke et al., 2000). With the end of the war, Wegener however shortly returned to Germany while Letzmann continued his studies of severe storms and tornadoes.

From 1919 to 1924 Wegener headed the Meteorological Department of Deutsche Seewarte in Hamburg. Frequent correspondence reveals that Wegener was extremely insistent that Letzmann join him in Hamburg with a suitable research position. However he obtained a teaching position at Dorpat University and remained there until the dawn of World War II.

His Ph.D. thesis (Letzmann, 1923), summarized by Letzmann (1925), contained groundbreaking analytical work on near-surface tornado windfields and damage. Both scientists maintained close collaboration on tornadoes and friendship until Wegener's death in Greenland in 1930.

During the 1930s Letzmann had become a major tornado researcher, including theory of vortex dynamics, details of earlier tornadoes, damage swath investigations, case histories, photographic sequence analysis, and laboratory simulations. Along with Harald Koschmieder and on behalf of the International Meteorological Organisation, he prepared guidelines to the study of tornadoes which were officially resolved in 1937 but appeared in print only two years afterwards (Koschmieder and Letzmann, 1939; Letzmann, 1939).

In 1940, Letzmann came to the University of Graz on the invitation of Kurt Wegener. Here, he could establish a research facility for atmospheric vortices (*Forschungsstelle für atmosphärische Wirbel*) and received the title of an adjunct professor. However, in late 1945 he lost his position at the university, and his professorship was withdrawn. With an increasingly difficult private situation over his long-lasting struggle to re-establish his lectureship, he moved to the German island of Langeoog in 1962, where he stayed in a facility for elderly Baltic Germans. He continued studies on tornadoes until his death in 1971, but at this time his work was nearly forgotten both in Germany and the USA.

Alfred Wegener was able to provide fruitful inspiration to the younger Letzmann by his own visionary work on tornadoes. This led to a remarkable list of papers (cf. Peterson, 1992a) which gain their full value only today with availability of mobile Doppler radars (e. g. Lee and Wurman, 2005), computer models (e. g. Lewellen et al., 1997), and detailed damage assessments (e. g. Wurman and Alexander, 2005; Wurman et al., 2007) as envisioned by Letzmann decades ago.

2.2 Analytical near-surface tornado wind field model

Letzmann had presented the full analytical derivation of his near-surface tornado wind field model only in his Ph.D. thesis[1] (Letzmann, 1923). The summary which appeared two years later in the *Meteorologische Zeitschrift* was detailed but less technical (Letzmann, 1925). Letzmann started from the assumption that the velocity field in a tornado vortex could be described by a Rankine vortex with a solid body rotation in the core up to the radius of

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[1] As the Ph.D. thesis is not easy to obtain today, it has been made available online in digitised form on the ESSL website, and paper copies of the specimen from Letzmann's legacy are available from the first author upon request.

maximum winds, followed by a hyperbolic decay of both the tangential and radial wind speeds for larger radii, called the “mantle” by Letzmann. The ratio between the two vortex wind components determined the angle of deflection (*Ablenkungswinkel*) α. A further key parameter describing the flow field was G, the ratio between rotational and translational motion of the tornado, and finally, ψ denoted the angle between the local instantaneous wind speed in a given point versus the direction of translation of the tornado.

This nomenclature was introduced by Peterson (1992a) in his review of Letzmann’s work, and also Holland et al. (2006) apply it in their paper. Clearly, their wind field model description is a reiteration of the main parts of Letzmann’s analytical model. While other authors like Wurman and Alexander (2005) also assume Rankine-type vortices, only Holland et al. (2006) directly follow the analytical formalism as set out by Letzmann (1923).

Holland et al. (2006) used velocity ratios G_{max} varying between 2.1 and 20, while Letzmann (1923, 1925) started his range of parameters G already below the critical value $G_{max} = 1$, and found that for $G_{max} < 1$, the flow field loses some of its vortex characteristics and corresponds more to a wave pattern. Interestingly, Letzmann focused on the case $G_{max} \approx 6$, which he assumed representative of tornadoes in the USA. Furthermore, we note that Holland et al. (2006) only treat the case of α = const., while Letzmann allowed for values of α variable with radius.

In creating the resulting streamline diagrams, Letzmann could rely on earlier work by Sandström (1909), which he developed further to his “method of individual circles” (*Methode der Individualkreise*). This technique allowed him to identify singular lines (*singuläre Linien*) of convergence and divergence lines within the vortex, as well as the locations of calms. In those vortices which contained a closed singular line, a “genuine core” (*echter Kern*) was present if the singular line showed convergence on both sides (outflow in the centre of the vortex), while a “false core” (*unechter Kern*) was present if the singular line showed a convergence-divergence couplet (inflow at the vortex’ centre). In modern terminology, this corresponds to the distinction between a two-cell and a one-cell tornado, respectively.

For $G_{max} \geq 1$, two other types of singular lines become discernible in the vortex: First, a “separation line” (*Grenzlinie*) dividing two regions of the vortex in which the streamlines enter the vortex from the rear side and either leave the vortex at the front side or converge into the separation line. Second, a “blocking line” (*Sperrlinie*) which surrounds an area of the vortex in which streamlines entering from the rear flank cannot reach the vortex front side, but converge either towards the central calm or to the separation line. By identifying these different lines and their locations in a reconstructed streamline diagram, Letzmann (1923, 1925) was able to study a wide range of specified vortex setups. It should further be noted that his analysis was derived in principle for any kind of vortex, and he consequently treated tropical and extratropical cyclones as well to underpin the general applicability of his analytical approach.

Before turning towards Letzmann's application of his method to forest damage patterns, we finally address the issue of the "hand calculations" and "hand-drawn diagrams" mentioned by Peterson (1992a) and Holland et al. (2006) in order to shed light on the soundness of this method of streamline reconstruction. The technique was developed by Sandström (1909), and the Letzmann legacy contains a later-published whole textbook on graphical streamline reconstruction.

Thus, Letzmann (1925) refers to the "Sandström technique" which was likely motivated by its relevance to produce streamline maps in synoptic meteorology: After computing the isogone fields for a given flow field, the streamlines obeying the equation

$$\frac{\mathrm{dy}}{\mathrm{dx}} = f(x, y) \qquad (1)$$

could be obtained graphically, or for a larger number of fields or a parameter study also mechanically. Sandström (1909) describes a mechanical device (cf. Fig. 1a) which was developed by his student V. Söderberg and which was able to graphically solve about 100 differential equations like Eq. (1) per day. Sandström (1909) presents a large number of worked-out examples of idealised and synoptic isogone and streamline fields, of which we show one quite complex specimen in Fig. 1b.

2.3 Guidelines for tornado research and forest damage surveys

Letzmann's guidelines for the study of tornadoes were resolved by the IMO in September 1937 (Salzburg, 14 September 1937, Resolution IV) following earlier recommendations by the Climatological Commission of the IMO to the member states to pay more attention to tornadoes (Danzig, 1935. Publ. Nr. 25, p. 21). The authors are presently unaware if IMO resolutions from that time still bear validity in the context of present-day WMO regulations.

The IMO guidelines from 1937 appeared in print two years afterwards[2] (Koschmieder and Letzmann, 1939; Letzmann, 1939) and were only slightly revised later on by Letzmann

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[2] Both Koschmieder and Letzmann (1939) and Letzmann (1939) are available online on the ESSL website.

(1944). After falling into oblivion for decades, they have been reviewed by Peterson (1992a) and translated to English (Peterson, 1992b), as well as summarised and augmented by an F-scale wind damage description adapted to Central Europe by Dotzek et al. (2000). Both Peterson (1992a,b) and Dotzek et al. (2000) show their being well ahead of their time.

Yet, not only had the advent of World War II prevented their widespread international application, but also in particular for the USA the sceptical commenting letters by J. B. Kincer, then-Cief of Division of Climate and Crop Weather at the US Weather Bureau, in which he expressed little confidence that ambitious tornado research programs as proposed in Letzmann's guidelines could ever be accomplished. These letters were attached to Koschmieder and Letzmann (1939), and one of them was reproduced and discussed by Peterson (1992b).

Based on his streamline analysis, Letzmann (1923, 1925, 1928) had produced images of tree fall pattern along cross-sections of a tornado damage swath for various combinations of the parameters α and G_{max} (cf. Fig. 11 of Peterson, 1992a). To do so, he had assumed that tree fall always occurred in the direction of the instantaneous wind at the location of the tree in the moment of its failure. The same assumption was also made by Holland et al. (2006). Letzmann then categorised the resulting swath patterns into four main types and showed these for six discrete values of the angle of deflection α. This diagram also appeared in the IMO guidelines (Letzmann, 1939) and has been reproduced by Peterson (1992a, Fig. 8), Peterson (1992b, Figs. 1 and 2) and Dotzek et al. (2000, Figs. 1 and 2) and hence is not included here again.

When compared to individual swath cross-sections (horizontal rows) of Holland et al. (2006, Figs. 9-15), their resemblance to Letzmann's characteristic swath types is striking. The only significant step forward by Holland et al. (2006) is the inclusion of the detailed tree response model which was unavailable in Letzmann's times. What Letzmann (1923) did investigate, however, was the effect of wind-induced torsion on trees, following the descriptions by Martins (1850) and Wegener (1917). He identified regions inside the vortex which might support twisting off trees by the vortex itself (cf. Fig. 12 of Peterson, 1992a), instead of the more common case where an asymmetric tree crown exposed to a more straight-line wind can also lead to a twisted fracture of the trunk.

For completeness, we mention that Letzmann's IMO guidelines also gave an extensive treatment on how to conduct ground and aerial damage surveys to provide the best possible data of the forest damage swath to enable proper reconstruction of the tornado characteristics. Given that the technique of aerial damage surveys was only later taken up and developed to full maturity by Ted Fujita (e. g. Fujita, 1981), we can only speculate what fruitful cooperation could have resulted if Letzmann and Fujita had the chance to work together on tornado damage analysis.

3 Conclusions

We welcome the paper by Holland et al. (2006) very much for their addressing a line of research directly linked to Letzmann's investigations in the 1920s and 1930s. However, the following points are important to put Letzmann's work in a proper perspective:

- Based on the limited information they had on Letzmann's work, Holland et al. (2006) have apparently reinvented parts of Letzmann's analytical tornado vortex model;
- The full versatility of the analysis by Letzmann (1923, 1925) remains yet to be exploited by Holland et al. (2006) and other groups addressing tornado damage assessments;
- We have provided here the necessary background and references to Letzmann's work and thus hope to stimulate further use of Letzmann's results for development or refinement of forest damage models such as that of Holland et al. (2006).

We are confident that Letzmann's achievements still can foster contemporary tornado research. The well-documented forest damage swath of the 2 October 2006 F3 Quirla tornado in Germany might serve as a test case to apply the Holland et al. (2006) model over hilly terrain.

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References

Dotzek, N., G. Berz, E. Rauch, and R. E. Peterson, 2000: Die Bedeutung von Johannes P. Letzmanns "Richtlinien zur Erforschung von Tromben, Tornados, Wasserhosen und Kleintromben" für die heutige Tornadoforschung. (The relevance of Johannes P. Letzmann's "Guidelines for research on tornadoes, waterspouts, and whirlwinds" for contemporary tornado research). *Meteorol. Z.*, **9**, 165-174. [In German, with English abstract, available at essl.org/people/dotzek/]

Dotzek, N., 2003: An updated estimate of tornado occurrence in Europe. *Atmos. Res.*, **67-68**, 153-161.

Fujita, T. T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.*, **38**, 1511-1534.

Hall, F., and R. D. Brewer, 1959: A sequence of tornado damage patterns. *Mon Wea. Rev.*, **87**(6), 207-216.

Holland, A. P., A. J. Riordan, and E. C. Franklin, 2006: A simple model for simulating tornado damage in forests. *J. Appl. Meteor. Climatol.*, **45**, 1597-1611.

Hubrig, M., 2004. Analyse von Tornado- und Downburst-Windschäden an Bäumen (Analysis of tornado and downburst wind damage to trees). *Forst und Holz*, **59**, 78-84. [In German, with English abstract, available at tordach.org].

Koschmieder, H., and J. P. Letzmann, 1939: *Erforschung von Tromben (Research on tornadoes)*. Int. Meteor. Org., Klimatol. Komm., Protokolle der Tagung in Salzburg, 13.-17. September 1937, Publ. **38**, Leyde, Anlage XI, 85-90. [In German, with commenting English letters by J. B. Kincer, U. S. Weather Bureau, available at essl.org/pdf/-Letzmann1939/Koschmieder-Letzmann1939.pdf]

Lee, W.-C., and J. Wurman, 2005: Diagnosed three-dimensional axisymmetric structure of the Mulhall tornado on 3 May 1999. *J. Atmos. Sci.*, **62**, 2373-2393.

Letzmann, J. P., 1923: *Das Bewegungsfeld im Fuß einer fortschreitenden Wind- oder Wasserhose (The flow field at the base of an advancing tornado)*. Dissertation Thesis, Acta et Commentationes Universitatis Dorpatensis **AVI.3**, C. Mattiesen Verlag, Dorpat, 136 pp. [In German, available at essl.org/pdf/Letzmann1923/Letzmann1923.pdf]

Letzmann, J. P., 1925: Fortschreitende Luftwirbel (Advancing air vortices). *Meteorol. Z.*, **42**, 41-52. [In German]

Letzmann, J. P., 1928: Zur Methodik der Trombenforschung (On the methodology of tornado research). *Meteorol. Z.*, **45**, 434-439. [In German]

Letzmann, J. P., 1939: *Richtlinien zur Erforschung von Tromben, Tornados, Wasserhosen und Kleintromben (Guidelines for research on tornadoes, waterspouts, and whirlwinds).* Int. Meteor. Org., Klimatol. Komm., Protokolle der Tagung in Salzburg, 13.-17. September 1937, Publ. **38**, Leyde, Anlage XI, 91–110. [In German, available at essl.org/pdf/-Letzmann1939/Letzmann1939.pdf]

Letzmann, J. P., 1944: *Richtlinien zur Erforschung von Tromben, Tornados, Wasserhosen und Kleintromben (Guidelines for research on tornadoes, waterspouts, and whirlwinds).* Universität Graz, 32 pp. [In German]

Lewellen, W. S., D. C. Lewellen, and R. I. Sykes, 1997: Large-eddy simulation of a tornado's interaction with the surface. *J. Atmos. Sci.*, **54**, 581–605.

Lüdecke, C., E. Tammiksaar, and U. Wutzke, 2000: Alfred Wegener und sein Einfluss auf die Meteorologie an der Universität Dorpat (Tartu) (Alfred Wegener and his influence on meteorology at the university of Dorpat (Tartu)). *Meteorol. Z.*, **9**(3), 175-183. [In German, with English abstract]

Martins, C., 1850: Anweisung zur Beobachtung der Windhosen oder Tromben (Instructions for tornado observations). *Poggend. Ann. Phys.*, **81**, 444–467. [In German]

Peterson R. E., 1992a: Johannes Letzmann: A pioneer in the study of tornadoes. *Wea. Forecasting*, **7**(1), 166-184.

Peterson R. E., 1992b: Letzmann's and Koschmieder's "Guidelines for research on funnels, tornadoes, waterspouts and whirlwinds". *Bull. Amer. Meteor. Soc.*, **73**(5), 597-611.

Peterson R. E., 1995: *Johannes Peter Letzmann: Pioneer tornado researcher*. In: Eelsalu, H., and H. Tooming (Eds.), Meteorology in Estonia in Johannes Letzmann's times and today. Estonian Academy Publishers, Tallinn, 9-43.

Reye, T., 1872: *Die Wirbelstürme, Tornados und Wettersäulen in der Erdatmosphäre mit Berücksichtigung der Stürme in der Sonnen-Atmosphäre (The cyclones and tornadoes in the earth's atmosphere, considering also storms in the solar atmosphere).* Carl Rümpler, Hannover, 250 pp. [In German, available at essl.org]

Sandström, J. W., 1909: Über die Bewegung der Flüssigkeiten (On the motion of fluids). *Ann. Hydrogr. Marit. Meteor.*, **37**, 242-254, with 7 plates. [In German]

Wegener, A., 1917: *Wind- und Wasserhosen in Europa (Tornadoes in Europe).* Verlag Friedrich Vieweg und Sohn, Braunschweig, 301 pp. [In German, available at essl.org].

Wurman, J., and C. R. Alexander, 2005: The 30 May 1998 Spencer, South Dakota, storm. Part II: Comparison of observed damage and radar-derived winds in the tornadoes. *Mon. Wea. Rev.*, **133**, 97-119.

Wurman, J., C. Alexander, P. Robinson, and Y. Richardson, 2007: Low-level winds in tornadoes and potential catastrophic tornado impacts in urban areas. *Bull. Amer. Meteor. soc.*, **88**(1), 31-46.

Figure captions

Fig. 1: (a) Söderberg's apparatus for graphical solution of differential equations, as used by Sandström (1909, Fig. 3) for construction of isogones and streamlines, and (b) example of graphical solution of the streamline equation $dy/dx = \tan [3\pi \sin (x^2 + y^2)^{1/2}]$ from Sandström (1909, Plate 32).

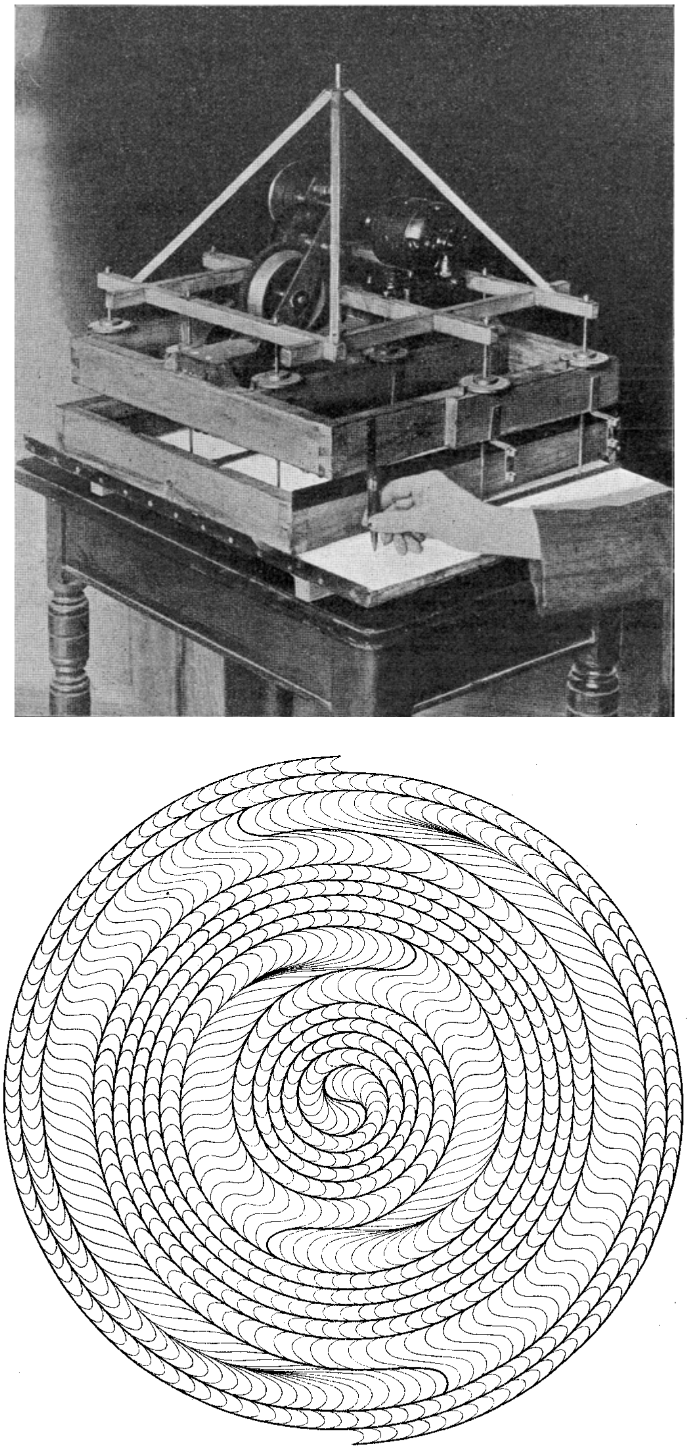

Fig. 1: (a) Söderberg's apparatus for graphical solution of differential equations, as used by Sandström (1909, Fig. 3) for construction of isogones and streamlines, and (b) Example of graphical solution of the streamline equation $dy/dx = \tan[3\pi \sin(x^2 + y^2)^{1/2}]$ from Sandström (1909, Plate 32).