

TECHNOLOGICAL UNIVERSITY DELFT

DEPARTMENT OF AERONAUTICAL ENGINEERING

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THEORETICAL AND EXPERIMENTAL INVESTIGATIONS
OF INCOMPRESSIBLE LAMINAR BOUNDARY LAYERS
WITH AND WITHOUT SUCTION

Ph.D THESIS

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DELFT
the NETHERLANDS

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This PDF-file contains chapter 13:

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13. References.

1. Smith, A.M.O., Gamberoni, N.: Transition, pressure gradient, and stability theory. Report ES 26388, Douglas Aircraft Co, 1956.
2. Smith, A.M.O.: Transition, pressure gradient and stability theory. Proc. 9th Int. Congr. Appl. Mech, Brussels, 4, p 234-244, 1956.
3. Ingen, J.L. van: Een semi-empirische methode voor de bepaling van de ligging van het omslaggebied van de grenslaag bij onsamendrukbare tweedimensionale stromingen (in Dutch). Rept VTH-71. Dept. Aeron. Eng. Delft, 1956.
4. Ingen, J.L. van: A suggested semi-empirical method for the calculation of the boundary layer transition region. Rept VTH-74, Dept. Aeron. Eng., Delft, 1956.
5. Ingen, J.L. van: (same title as [4]); Proc. Second. European Aeron. Congr., Scheveningen, Netherlands, 1956.
6. Melvill Jones, B.: The streamline aeroplane. Journal Royal Aeron. Soc. 33, p 357, 1929.
7. Schlichting, H.: Grenzschichttheorie. G. Braun, Karlsruhe, third edition, 1958. (see also Boundary layer theory, English edition, Pergamon Press, London, 1955).
8. Griffith, A.A., Meredith, F.W.: The possible improvement in aircraft performance due to the use of boundary layer suction. ARC Rept 2315, 1936.
9. Lachmann, G.V.: Boundary layer and flow control; its principles and applications. 2 vols, Pergamon Press, 1961.
10. Lachmann, G.V.: Aspects of design, engineering and operational economy of low drag aircraft. pp 1123-1165 of [9].
11. Holstein, H.: Versuche zur Grenzschichtbeeinflussung. Göttinger Monograph, part B4, 1945.
12. Pfenniger, W.: Untersuchungen über Reibungsverminderungen an Tragflügeln insbesondere mit Hilfe von Grenzschichtabsaugung. Mitt. Inst. Aerodyn., E.T.H. Zürich, no 13, 1946 (see also N.A.C.A. TM 1181, 1947).
13. Kay, J.M.: Boundary-layer flow along a flat plate with uniform suction. A.R.C. R and M 2628, 1948.
14. Head, M.R.: The boundary layer with distributed suction. A.R.C., R and M 2783, 1951.

15. Head, M.R., Johnson, D. and Coxon, M.: Flight experiments on boundary layer control for low drag. A.R.C. R and M 3025, 1955.
16. Pfenniger, W. and Groth, E.: Low drag boundary layer suction experiments in flight on a wing glove of an F-94A airplane with suction through a large number of fine slots. p 981-999 in [9].
17. Pfenniger, W. and Bacon, J.W.: About the development of swept laminar suction wings with full chord laminar flow. p 1007-1032 in [9].
18. Gregory, N.: Research on suction surfaces for laminar flow. pp 924-960 of [9].
19. - : Recent developments in boundary layer research. Proceedings of Agard Specialist Meeting, Naples, may 1965, Agardograph 97.
20. Pfenniger, W.: Some results of the X-21 program, Part 1: Flow phenomena at the leading edge of swept wings. In [19].
21. Fowell, L.R. and Antonatos, P.P.: Some results of the X-21 A program, Part 2: Laminar flow flight test results on the X-21A. In [19].
22. Pohlhausen, K.: Zur näherungsweise Integration der Differentialgleichung der laminaren Grenzschicht. Z.A.M.M. 1, p 252-268, 1921.
23. Jeffery, G.B.: The two-dimensional steady motion of a viscous fluid. Phil. Mag. 6, 29, p 455-465, 1915.
24. Hamel, G.: Spiralförmige Bewegungen zäher Flüssigkeiten. Jahrbuch deutsch. Math. Ver. 25, 1916, p 34-60.
25. Schubauer, G.B.: Air flow in a separating laminar boundary layer. N.A.C.A. Rept 527, 1935.
26. Hartree, D.R.: The solution of the equations of the laminar boundary layer for Schubauer's observed pressure distribution for an elliptic cylinder. A.R.C., R and M 2427, 1939.
27. Prandtl, L.: Über Flüssigkeitsbewegung bei sehr kleiner Reibung. Verh. III int. Math. Kongr., Heidelberg, p 484-491, 1904.
28. Curle, N.: The laminar boundary layer equations. Clarendon Press, Oxford 1962.
29. Rosenhead, L.: Laminar boundary layer theory. Clarendon Press, Oxford 1963.
30. Kármán, Th. von: Über laminare und turbulente Reibung. Z.A.M.M. 1, p 233-252, 1921.

31. Leibenson, L.S.: The energy form of the integral condition in the theory of the boundary layer. Dokl. Ak. Nauk. S.S.S.R. 2, p 22-24, 1935.
32. Wieghardt, K.: Über einen Energiesatz zur Berechnung laminarer Grenzschichten. Ingen.-arch. 16, p 231-242, 1948.
33. Blasius, H.: Grenzschichten in Flüssigkeiten mit kleiner Reibung. Z. Math. Phys. 56, p 1-37, 1908. (see also NACA TM 1256).
34. Hiemenz, K.: Die Grenzschicht an einem in den gleichförmigen Flüssigkeitsstrom eingetauchten geraden Kreiszylinder. Diss. Göttingen 1911, Dingl. Polytechn. J. 326, 32, 1911.
35. Goldstein, S.: A note on the boundary layer equations. Proc. Cambr. Phil. Soc. 35, 338, 1939.
36. Mangler, W.: Die ähnlichen Lösungen der Prandtl'schen Grenzschichtgleichungen. Z.A.M.M. 23, p 241-251, 1943.
37. Mangler, W. Special exact solutions, section 1.2 of Boundary Layers, Göttinger Monograph, 1948.
38. Falkner, V.M., Skan, S.W.: Some approximate solutions of the boundary-layer equations. A.R.C., R and M 1314, 1930. (see also Solutions of the boundary-layer equations. Phil. Mag. 7, 12, p 865-896, 1931).
39. Hartree, D.R.: On an equation occurring in Falkner and Skan's approximate treatment of the equations of the boundary layer. Proc. Camb. Phil. Soc. 33, p 223-239, 1937.
40. Goldstein, S.: On backward boundary layers and flow in converging passages. J. Fluid Mech. Vol. 21, part 1, pp 33-45, 1965.
- 41a Hegge Zijnen, B.G. van der: Measurements of the velocity distribution in the boundary layer along a plane surface. Thesis, Delft, 1924.
- 41b Burgers, J.M.: Proc. First. Int. Congr. Appl. Mech., Delft 1924.
42. Hansen, M.: Die Geschwindigkeitsverteilung in der Grenzschicht an einer eingetauchten Platte. ZAMM, 8, 185, 1928. (see also NACA TM 585, 1930).
43. Howarth, L.: On calculation of the steady flow in the boundary layer near the surface of a cylinder in a stream. A.R.C. R and M 1632, 1934.
44. Howarth, L.: On the solution of the laminar boundary layer equations. Proc. Roy. Soc. A. 164, 547-579, 1938.

45. Tani, I.: On the solution of the laminar boundary layer equations.
Journ. Phys. Soc. Japan, 4, 149-154, 1949.
46. Görtler, H.: A new series for the calculation of steady laminar
boundary layer flows. J. Math. Mech. 6, p 1-66, 1957.
47. Görtler, H. and Witting, H.: Zu den Tanischen Grenzschichten,
Österr. Ing. Arch. 11, 111-122, 1957.
48. Görtler, H.: Zahlentafeln universeller Funktionen zur neuen Reihe
für die Berechnung laminarer Grenzschichten. D.V.L.-Bericht 34,
1957.
49. Görtler, H.: On the calculation of steady laminar boundary layer
flows with continuous suction. J. Math. Mech. 6, p 323-340, 1957.
50. Holstein, H., Bohlen, T.: Ein einfaches Verfahren zur Berechnung
laminarer Reibungsschichten, die dem Näherungsansatz von K.Pohlhausen
genügen. Bericht Lilienthal Ges. Luftfahrtf. S10, p 5-16.
51. Walz, A.: Ein neuer Ansatz für das Geschwindigkeitsprofil der laminaren
Reibungsschicht. Lilienthal-Bericht 141, 8, 1941.
52. Timman, R.: A one-parameter method for the calculation of laminar
boundary layers. N.L.L. Rept F-35, 1949.
53. Zaat, J.A.: A one parameter method for the calculation of the
temperature profile of laminar incompressible boundary layer flow with
a pressure gradient. Rept F-127; Nat. Aeron. Res. Inst. (N.L.L.),
Amsterdam, 1953.
54. Nunnink, H.J.C.A.: One parameter methods for the calculation of
laminar boundary layers of two-dimensional incompressible flows.
Rept 18, Institute for Applied Math, Delft, 1957.
55. Schlichting, H.: Ein Näherungsverfahren zur Berechnung der laminaren
Reibungsschicht mit Absaugung. Ing. Arch. 16, p 201, 1948.
56. Truckenbrodt, E. Ein einfaches Näherungsverfahren zum Berechnen der
laminaren Reibungsschicht mit Absaugung. Forsch. Ing. Wes. 22,
p 147, 1956.
57. Thwaites, B.: Approximate calculation of the laminar boundary layer.
Aeron. Quart. 1, p 245-280, 1949.
58. Curle, N. and Skan, S.W.: Approximate methods for predicting separation
properties of laminar boundary layers. Aeron. Quart. 8, 257-268, 1957.

59. Walz, A.: Anwendung des Energiesatzes von Wieghardt auf einparametrische Geschwindigkeitsprofile in laminaren Grenzschichten. Ing. Arch. 16, 243-248, 1948.
60. Tani, I.: On the approximate solution of the laminar boundary layer equations. J. Aero. Sci. 21, 487-495, 504, 1954.
61. Truckenbrodt, E.: Ein Quadraturverfahren zur Berechnung der laminaren und turbulenten Reibungsschichten bei ebener und rotations-symmetrischer Strömung. Ingen.-Arch. 20, 211-228, 1952.
62. Head, M.R.: An approximate method of calculating the laminar boundary layer in two-dimensional incompressible flow. A.R.C., R and M 3123, 1957.
63. Head, M.R.: Approximate calculations of the laminar boundary layer with suction, with particular reference to the suction requirements for boundary layer stability on aerofoils of different thickness-chord ratio. A.R.C., R and M 3124, 1957.
64. Head, M.R.: Approximate methods of calculating the two-dimensional laminar boundary layer with suction. pp 801-841 of [9].
65. Ingen, J.L. van: Een tweeparametermethode voor de berekening van de laminaire grenslaag met afzuiging. (in Dutch). Memorandum M1, Dept. Aeron. Eng., Delft, 1958.
66. Thwaites, B.: An exact solution of the boundary layer equations under particular conditions of porous surface suction. A.R.C. R and M 2241, 1946.
67. Iglisch, R.: Exakte Berechnung der laminaren Grenzschicht an der längsangeströmten ebenen Platte mit homogener Absaugung. Schr. dtisch. Akad. Luftfahrtf. 8B, pl-51. (see also N.A.C.A. T.M. 1205).
68. Poincaré, H.: Sur les courbes définies par une equation differentielle. Oeuvre, Gauthier-Villars, Paris Vol 1, 1892.
69. Minorsky, N.: Nonlinear oscillations. Van Nostrand Co. Princeton, 1962.
70. Stoker, J.J.: Nonlinear vibrations in mechanical and electrical systems. Intersc. Publ. 1950.
71. Ingen, J.L. van: Phaseplane representation of the incompressible viscous flow between non-parallel plane walls. Rept VTH-118, Dept. Aeron. Eng. Delft, 1964.

72. Ku, Y.K.: Boundary layer problems solved by the method of non-linear mechanics. Proc. 9th Intern. Congr. Appl. Mech., Brussels, 1956, p 132-144.
73. Holstein, H. Ähnliche laminare Reibungsschichten an durchlässigen Wänden. UM 3050, 1943.
74. Pretsch, J.: Die laminare Grenzschicht bei starkem Absaugen und Ausblasen. UM 3091, 1944.
75. Crocco, L.: A characteristic transformation of the equations of the boundary layer in gases. A.R.C., London, Rept 4582 (translated from Atti di Guidonia 17, no 7, p 118, 1939).
76. Schönauer, W.: Ein Differenzenverfahren zur Lösung der Croccoschen Grenzschichtgleichung für laminare inkompressible Strömung. Diss. Karlsruhe, 1960.
77. Schönauer, W.: Ein Differenzenverfahren zur Lösung der Croccoschen Grenzschichtgleichung für laminare inkompressible Strömung, ZAMM, Band 42, Sonderheft p 162-164, 1962.
78. Zonneveld, J.A.: Automatic numerical integration. Mathematical Centre Tracts, 8, Amsterdam 1964.
79. Trilling, L.: The incompressible boundary layer with pressure gradient and suction. J.Aeron. Sci, 17, p 335-342, 1950.
80. Dorodnitsyn, A.A.: General method of integral relations and its application to boundary layer theory. Proc. Sec. Int. Congress Aeron. Sciences, Zürich, sept 1960, vol.3, p 207-219.
81. Hartree, D.R.: A solution of the laminar boundary-layer equation for retarded flow. A.R.C., R and M 2426, 1939.
82. Leigh, D.C. The laminar boundary-layer equation: A method of solution by means of an automatic computer. Proc. Camb. Phil. Soc. 51, p 320-332, 1955.
83. Terrill, R.M.: Laminar boundary-layer flow near separation with and without suction. Phil. Trans. A 252, p55-100, 1960.
84. Goldstein, S.: On laminar boundary-layer flow near a position of separation. Quart. J.Mech. 1, p 43-69, 1948.
85. Curle, N.: Accurate solutions of the laminar-boundary-layer equations, for flows having a stagnation point and separation. ARC, R and M 3164.

86. Rheinboldt, W.: Zur Berechnung stationärer Grenzschichten bei kontinuierlicher Absaugung mit un stetig veränderlicher Absauggeschwindigkeit. J. Rat. Mech. Anal. 5, p 539-604, 1956.
87. Schubauer, G.B., Skramstad, H.K. Laminar boundary layer oscillations and transition on a flat plate. N.A.C.A. Rept 909, 1947.
88. Reynolds, O.: An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous, and of the law of resistance in parallel channels. Phil. Trans. 174, p 935-982, 1883.
89. Taylor, G.I.: Statistical theory of turbulence. V. Effect of turbulence on boundary layer. Proc. Roy. Soc. London, Ser. A, vol. 156, no 888, 1936, p 307-317.
90. Lin, C.C.: The theory of hydrodynamic stability. Cambridge University Press, 1955.
91. Malotaux, P.C.A. et. al.: A method for qualitative boundary layer investigations by means of hot-wires without disturbing the flow. Rept. VTH-45, Dept. Aeron. Eng., Delft, 1951 (in Dutch with English summary).
92. Hinze, J.O. et.al. Contribution a la transition dans la couche limite. Compt. Rend. 8^{èmes} Journées de l'Hydraulique. Société Hydrotechnique de France, Lille, 1964.
- 93a Schubauer, G.B., Klebanoff, P.S.: Contributions on the mechanics of boundary layer transition. Proc. Symp. boundary layer effects in Aerodyn. N.P.L. 1955.
- 93b Schubauer, G.B.: Mechanism of transition at subsonic speeds. Proc. Symp. Boundary Layer Research, Int. Union theoret. appl. Mech. Freiburg p 85-109, 1957.
94. Klebanoff, P.S., Tidstrom, K.D.: The evolution of amplified waves leading to transition in a boundary layer with zero pressure gradient. N.A.C.A. T.N. D-195, 1959.
95. Squire, H.B. On the stability for three-dimensional disturbances of viscous fluid flow between parallel walls. Proc. Roy. Soc. A 142, p 621-628, 1933.

96. Pretsch, J.: Die Stabilität einer ebenen Laminarströmung bei Druckgefälle und Druckanstieg. Jb. dtsh. Luftfahrtforsch. 1, p 158-75, 1941.
97. Pretsch, J.: Die Anfachung instabiler Störungen in einer laminaren Reibungsschicht. Jb. dtsh. Luftfahrtf. p 154-171, 1942.
98. Pretsch, J.: Berechnung der Stabilitätsgrenze von Grenzschichtprofilen und der Anfachung von Störungen. Göttinger Monograph. Part B.3.2. 1945.
99. Ulrich, A.: Theoretische Untersuchungen über die Widerstandersparnis durch Laminarhaltung mit Absaugung. Schr. dtsh. Akad. Luftfahrtf. 83, p 53 (see also N.A.C.A. TM 1121).
100. Freeman, J.C. and Chiarulli, P.: Stability of the boundary layer. Tech. Rep. H.Q. Air Material Command. F-T/R-1197-1A, 1948.
101. Wieghardt, K.: Zur Berechnung ebener und drehsymmetrischer Grenzschichten mit kontinuierlicher Absaugung. Ing. Arch. 22, 368, 1954.
102. Lin, C.C.: On the stability of two-dimensional parallel flows. Quarterly Appl. Math. Vol 3, july 1945, p 117-142; vol 3, oct. 1945, p 218-234; Vol 3, jan. 1946, p 277-301.
103. Shen, S.F. Calculated amplified oscillations in plane Poiseuille and Blasius flows. J. Aero. Sci. 21, p 62-64, 1954.
104. Timman, R., Zaat, J.A., Burgerhout, Th. J.: Stability diagrams for laminar boundary layer flow. N.L.L. Rept F 193, 1956.
105. Tollmien, W.: Über die Entstehung der Turbulenz. 1. Mitteilung, Nachr. Ges. Wiss. Göttingen, Math. Phys. Klasse. 21-44, 1929 (also NACA TM 609, 1931).
106. Michel, R.: Détermination du point de transition et calcul de la trainée des profils d'ailes en incompressible. O.N.E.R.A. Rept no 58, 1952.
107. Granville, P.S. The calculation of viscous drag of bodies of revolution. David Taylor Model Basin, Rept 849, 1953.
108. Dobbinga, E. and Ghesel Grothe, J.A. van: De lage snelheidswindtunnel van de subafdeling Vliegtuigbouwkunde der Technische Hogeschool (in Dutch), De Ingenieur, 23 sept 1955, p A461.
109. Maas, H.J. van der: Aeronautical research in the Netherlands. J.Roy. Aeron. Soc. Vol 61, 1957, p 295-334.

- 110. Tennekes, H.: Beknopte handleiding voor het meten van de snelheid en de turbulentiegraad van luchtstromingen met de constante temperatuurapparatuur van de onderafdeling Vliegtuigbouwkunde. VTH-handleiding 56, 1961.
- 111. Pankhurst, R.C. and Holder, D.W.: Wind tunnel technique. Pitman, London, 1952.
- 112. Pfenniger, W.: Vergleich der Impulsmethode mit der Wägung bei Profilwiderstandsmessungen. Mitt. Inst. Aerodyn. ETH, Zürich no 8, 1943.
- 113. Squire, H.B., Young, A.D.: The calculation of the profile drag of aerofoils. A.R.C., R and M 1838, 1937.
- 114. Smith, A.M.O.: Improved solutions of the Falkner and Skan boundary-layer equation. Sherman M.Fairchild Fund Paper FF-10, Inst. Aero. Sci, 1954.
- 115. Schlichting, H. and Ulrich, A.: Zur Berechnung des Umschlages laminar-turbulent. Jahrbuch d. dt. Luftfahrtforschung I, 8, 1942.

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