Appendix B Sources of Experimental Data for Code Validation

Airfoil Data Sources

Some sources of airfoil geometry and experimental data for use in code evaluation are listed here. Note that rigorous validation of codes requires very careful analysis, and an understanding of possible experimental, as well as computational, error. See the junior Aerodynamic Lab notes for my comments on the issues involved in aerodynamic testing in wind tunnels. Hardcopies of the NACA reports are located in the Virginia Tech Library at DOCS Y3.N21/5:9 on the first floor.

Books

Abbott and von Doenhoff, *Theory of Airfoil Sections*. Look in the references for the original NACA airfoil reports. Note that pressure distributions are fairly rare. See also NACA R 824.

Riegels, *Airfoil Sections*, Butterworths, London, 1961. (English language version)

NASA Low and Medium Speed Airfoils

McGhee, Robert J., and Beasley, William D., "Low Speed Aerodynamic Characteristics of a 17-Percent-Thick Airfoil Section Designed for General Aviation Applications," NASA TN D-7428, 1973.

McGhee, Robert J., Beasley, William D., and Somers, Dan M., "Low Speed Aerodynamic Characteristics of a 13-Percent-Thick Airfoil Section Designed for General Aviation Applications," NASA TM X-72697, 1975.

McGhee, Robert J., and Beasley, William D., "Effects of Thickness on the Aerodynamic Characteristics of an Initial Low-Speed Family of Airfoils for General Aviation Applications," NASA TM X-72843, 1976.

McGhee, Robert J., and Beasley, William D., "Low-Speed Wind-Tunnel Results for a Modified 13-Percent-Thick Airfoil," NASA TM X-74018, 1977.

Barnwell, Richard W., Noonan, Kevin W., and McGhee, Robert J., "Low Speed Aerodynamic Characteristics of a 16-Percent-Thick Variable Geometry Airfoil Designed for General Aviation Application," NASA TP-1324, 1978.

McGhee, Robert J., and Beasley, William D., "Wind-Tunnel Results for an Improved 21-Percent-Thick Low-Speed Airfoil Section," NASA TM-78650, 1978.

McGhee, Robert J., Beasley, William D., and Whitcomb, Richard T., "NASA Low- and Medium-Speed Airfoil Development " NASA TM-78709, 1979.

McGhee, Robert J., and Beasley, William D., "Low-Speed Aerodynamic Characteristics of a 13-Percent-Thick Medium Speed Airfoil Designed for General Aviation Applications," NASA TP-1498, 1979.

McGhee, Robert J., and Beasley, William D., "Low Speed Aerodynamic Characteristics of a 17-Percent-Thick Medium Speed Airfoil Designed for General Aviation Applications," NASA TP-1786, 1980

McGhee, Robert J., and Beasley, William D., "Wind-Tunnel Results for a Modified 17-Percent Thick Low-Speed Airfoil Section, " NASA TP-1919, 1981. (LS(1)-0417mod)

Ferris, James D., McGhee, Robert J., and Barnwell, Richard W., "Low Speed Wind-Tunnel Results for Symmetrical NASA LS(1)-0013 Airfoil," NASA TM-4003, 1987.

NASA Transonic Airfoils

Whitcomb, "Review of NASA Supercritical Airfoils," ICAS Paper 74-10, August 1974 (ICAS stands for International Council of the Aeronautical Sciences)

Harris, C.D., "NASA Supercritical Airfoils," NASA TP 2969, March 1990. See references contained in this report for sources of experimental data.

Laminar Flow Airfoils

Somers, Dan M., "Design and Experimental Results for a Flapped Natural-Laminar-Flow Airfoil for General Aviation Applications," NASA TP-1865, June 1981. (NLF(1)-0215F, Lancair and Wheeler express airfoil)

McGhee, Robert J., Viken, Jeffrey K., and Pfenninger, Werner, D., "Experimental Results for a Flapped Natural-Laminar Flow Airfoil With High Lift/Drag Ratio," NASA TM-85788, 1984.

Sewell, W.G., McGhee, R.J., Viken, J.K., Waggoner, E.G., Walker, B.S., and Miller, B.F., "Wind Tunnel Results for a High-Speed, Natural Laminar Flow Airfoil Designed for General Aviation Aircraft," NASA TM 87602, No. 1985.

Other Low and Medium Speed Airfoils and Airfoil Data

Beasley, William D., and McGhee, Robert J., "Experimental and Theoretical Low-Speed Aerodynamic Characteristics of the NACA 65(1)-213, a = 0.50, Airfoil," NASA TMX-3160, Feb. 1975

Hicks, Raymond M., "A Recontoured Upper Surface Designed to Increase the Maximum Lift Coefficient of a Modified NACA 65(0.82) (9.9) Airfoil Section," NASA TM 85855, Feb. 1984.

Bingham, Gene J., and Chen, Allen Wen-shin, "Low Speed Aerodynamic Characteristics of an Airfoil Optimized for Maximum Lift Coefficient," NASA TN D-7071, Dec. 1971.

Stivers, "Effects of Subsonic Mach Number on the Forces and Pressure Distributions on Four 64A-Series Airfoil Sections at Angles of Attack as High as 28°," NACA TN 3162, 1954. Also see TN 2096?

Liebeck, R.H., "A Class of Airfoils Designed for High Lift in Incompressible Flow", *Journal of Aircraft*, Oct. 1973, Vol. 10, No. 10, pp. 610-617

Multi-element Airfoil Data

Wenzinger, C.J., and Delano, J., "Pressure Distribution Over an NACA 23012 Airfoil with a Slotted and Plain Flap," NACA R-633, 1938.

Harris, T.A., and Lowry, J.G., "Pressure Distribution over an NACA 23012 Airfoil with a Fixed Slot and a Slotted Flap," NACA R 732, 1942.

Axelson, J.A., and Stevens, G.L., "Investigation of a Slat in Several Different Positions on an NACA 64A010 Airfoil for a Wide Range of Subsonic Mach Numbers," NACA TN 3129, March 1954.

Weick, F.E., and Shortal, J.A., "The Effect of Multiple Fixed Slots and a Trailing-edge Flap on the Lift and Drag of a Clark Y Airfoil," NACA R 427, 1932.

Wentz, W.H., Jr., and Seetharam, H.C, "Development of a Fowler Flap System for a High Performance General Aviation Airfoil," NASA CR-2443, 1974

Seetharam, H.C., and Wentz, W.H., "Experimental Studies of Flow Separation and Stalling on a Two-Dimensional Airfoil at Low Speeds," NASA CR-2560, 1975.

Kelly, John A., and Hayter, N-L, F., "Lift and Pitching Moment at Low Speeds of the NACA 64A010 Airfoil Section Equipped with Various Combinations of Leading Edge Slat, Leading Edge Flap, Split Flap and Double-Slotter Flap," NACA TN 3007, Sep. 1953. (no drag or pressure distributions)

Other data sources:

Bertin and Smith, 1st edition , page 102-102, NACA 4412, pressure distribution, 2nd edition: pg 201-202, 3rd edition: pg 221-222 (from Pinkerton, NACA R 563, 1936, but WATCH OUT! This data is not what you might think. See NACA R-646 for true 2-D data!)

Hurley, F.X., Spaid, F.W., Roos, F.W., Stivers, L.S., Jr., and Bandettini, A., "Supercritical Airfoil Flowfield Measurements," AIAA Paper No. 75-880, June 1975.

Three-Dimensional Data Sources

Elementary body geometries: There were many tests conducted by the NACA using geometries that are simple to model. Similar tests were also done in the early days of NASA. The NACA reports were classified at the time, but have been declassified. A sample of cases I've used are included here:

Williams, C.V., "An Investigation of the Effects of a Geometric Twist on the Aerodynamic Loading Characteristics of a 45° Sweptback Wing-Body Configuration at Transonic Speeds," NACA RM L54H18, 1954.

Runckel, J.F., and Lee, E.E., Jr., "Investigation of Transonic Speeds of the Loading Over a 45° Sweptback Wing Having an Aspect Ratio of 3, Taper Ratio of 0.2, and NACA 65A004 Airfoil Sections," NASA TN D-712, 1961.

Loving, D.L., and Estabrooks, B.B., "Transonic Wing Investigation in the Langley Eight Foot High Speed Tunnel at High Subsonic Mach Numbers and at a Mach number of 1.2," NACA RM L51F07, 1951.

McDevitt, J.B., "An Experimental Investigation of Two Methods for Reducing Transonic Drag of Swept Wing and Body Combinations," NACA RMA55B21, April 1955.

Keener, E.R., "Pressure Measurements Obtained in Flight at Transonic Speeds for a Conically Cambered Delta Wing," NASA TM X-48, October 1959.

The standard transonic test case: the ONERA M6 wing has been used in practically every transonic code validation calculation ever published. The data is contained in AGARD AR-138 cited below.

Supercritical Wings:

Harris, C.D., and Bartlett, D.W., "Tabulated Pressure Measurements on a NASA Supercritical-Wing Research Airplane Model With and Without Fuselage Area-Rule Additions at Mach 0.25 to 1.00," NASA TM X-2634, 1972.

Harris, C.D., "Wind-Tunnel Measurements of Aerodynamic Load Distribution on a NASA Supercritical-WIng Research Airplane Configuration," NASA TM X-2469, 1972.

Montoya, L.C., and Banner, R.D., "F-8 Supercritical Wing Flight Pressure, Boundary Layer and Wake Measurements and Comparisons with Wind Tunnel Data," NASA TM X-3544, March 1977.

Hinson, B.L., and Burdges, K.P., "Acquisition and Application of Transonic Wing and Far-Field Test Data for Three-Dimensional Computational Method Evaluation," AFOSR-TR-80-0421, March 1980, available from DTIC as AD A085 258. These are the Lockheed Wings A, B, and C.

Keener, E.R., "Pressure Distribution Measurements on a Transonic Low-Aspect Ratio Wing," NASA TM 86683, 1985. (this is the so-called Lockheed Wing C)

Keener, E.R., “Boundary Layer Measurements on a Transonic Low-Aspect Ratio Wing,” NASA TM 88214, 1986. (this is the so-called Lockheed Wing C)

Supersonic Wing Data:

D.S. Miller, E.J. Landrum, J.C. Townsend, and W.H. Mason, “Pressure and Force Data for a Flat Wing and a Warped Conical Wing Having a Shockless Recompression at Mach 1.62,” NASA TP 1759, April 1981.

J.L. Pittman, D.S. Miller, and W.H. Mason, “Fuselage and Canard Effects on an Attached Flow, Maneuver Wing at Mach 1.62,” NASA TP 2249, February 1984

J.L. Pittman, D.S. Miller, and W.H. Mason, “Supersonic, Nonlinear, Attached-Flow Wing Design for High Lift with Experimental Validation,” NASA TP 2336, August 1984.

AGARD Test Cases

AGARD has selected test cases for CFD code validation. These cases are important because an attempt has been made to define the test conditions and any corrections required precisely enough for use in code validation work. This is not an easy job. This also means that the airfoil test coordinates and results are available in tabulated form in these reports. The reports include:

AGARD AR-138, “Experimental Data Base for Computer Program Assessment,” May, 1979

Two-dimensional test cases:

(1) NACA 0012, over a range of subsonic Mach and angle of attack, both force and moment and pressure distributions,

(2) NLR QE 0.11-0.75-1.375, a symmetrical airfoil designed to be shock free at a transonic design point, Mach range from 0.30 to 0.85, all at zero angle of attack,

(3) CAST 7, pressure distributions over a range of Mach from 0.40 to 0.80, α from -2° to 5°, also boundary layer measurements. No force and moment data;

(4) NLR7301, thick supercritical airfoil (16.5%), Mach from 0.30 to 0.85, a from -4° to + 4°, pressure, and force and moment;

(5) SKF 1.1/with maneuver flap, (French), Mach number from 0.50 to 1.2, force and moment and pressure over a limited range of angle of attack;

(6) RAE 2822, surface pressure distribution, boundary layer and wake rake surveys, over a range of Mach and α (this is one of the most complete sets of data in the report),

(7) NAE 75-036-13:2, Mach range from 0.5 to 0.84, α from 0 to 4° at M = 0.75, 2° for other Machs.

(8) MBB-A3 NASA 10% supercritical, M from 0.6 to 0.80, α from 0.5° to 2.5°.

Three dimensional cases:

(1) ONERA M6, pressure distributions,

(2) ONERA AFV D, variable sweep wing,

(3) MBB-AVA Pilot Model with supercritical wing,

(4) RAE Wing A,

(5) NASA Supercritical-Wing Research Airplane Model (actually the F-8, pressure distributions only).

Body alone configurations:

(1) 1.5D Ogive Circular Cylinder Body, L/D = 21.5,

(2) MBB Body of revolution No. 3,

(3) 10° cone-cylinder at α zero, M from 0.91 to 1.22,

(4) ONERA calibration body model C5, M from 0.6 to 1.0, α zero.

AGARD AR-138-ADDENDUM, "ADDENDUM to AGARD AR No. 138, Experimental Data Base for Computer Program Assessment," July, 1984

Five additional three-dimensional data sets were identified and included in the ADDENDUM

(B-6) Lockheed-AFOSR Wing A: Semi-span wing, M 0.62-0.84, α from -2° to 5°, RE on mac: 6 million

(B-7) Lockheed-AFOSR Wing B: Semi-span wing, M: 0.70 to 0.94, α from -2° to + 5°, Re on mac: 10 million

(B-8) ARA M100 Wing/body, full model, M: 0.50-0.93, α from -4° to +3°, Re on mac: 3.5 million

(B-9) ARA M86 Wing/body, full model, M: 0.50-0.82, α from 0° to +8°, Re on mac:2.8-3.7 million

(B-10) FFA Aircraft (SAAB A32A Lansen), M: 0.40-0.89, α from 0° to +10°, Re on mac: 10-30 million

AGARD R-702, "Compendium of Unsteady Aerodynamic Measurements," Aug. 1982.

Seven test cases are defined, five airfoils and two wings. The include:

Airfoils:

1. NACA 64006 with oscillating flap,
2. NACA 64A010 with oscillatory pitching,
3. NACA 0012 with oscillatory and transient pitching,
4. NLR 7301 airfoil with (i) oscillatory pitching and oscillating flap at NLR and (ii) with oscillating pitching (NASA Ames).

Wing data

1. RAE Wing A with an oscillating flap
2. NORA Model with oscillation about the swept axis.

AGARD AR-211, "Test Cases for Inviscid Flowfield Methods," May 1985.

Two dimensional test cases

NACA 0012 airfoil at	(1) M = 0.80, α = 1.25°,
	(2) M = 0.85, α = 1°,
	(3) M = 0.95, α = 0°,
	(4) M = 1.25, α = 0°,
	(5) M = 1.25, α = 7°,
RAE 2822 airfoil at	(6) M = 0.75, α = 3°,

NLR 7301 airfoil at	(7) M = 0.720957, α = .194°, (theoretical data)
Chiocchia-Nocilla at	(8) M = 0.769, α = 0°. (sharp le)
2-D Cascade test cases:	
HOBSON-1	(9) M = 0.476, a = 43.544°, Spacing, s/c = 1.0121
HOBSON-2	(10) M = 0.575, a = 46.123°, Spacing, s/c = 0.5259
Three-dimensional cases	
ONERA M6 airfoil at	(11) M = 0.84, α = 3.06°,
	(12) M = 0.92, α = 0°,
Butler wing at	(13) M = 2.50, α = 0°,
Dillner wing at	(14) M = 1.50, α = 15°,
	(15) M = 0.70, α = 15°,
NASA Ames swept wing at	(16) M = 0.833, α = 1.75°,
AGARD B at	(17) M = 1.5,α = 0°,
	(18) M = 1.5,α = 2°,
	(19) M = 2.0, α = 0°,
	(20) M = 2.0,α = 2°.

AGARD AR-303, "A Selection of Experimental Test Cases for the Validation of CFD Codes," Aug. 1994. (in two volumes)

By now the data is much more elaborate, and there are many more cases.

A - Airfoil cases (13)

B - Wing-fuselage (6)

C - Bodies (6)

D - Delta wing class (5)

E - Aero-Propulsion/Pylon/Store (9)

The data is available on floppy disks. The Virginia Tech Library has this data in the media center. According to the report the data is available from the NASA Center for Aerospace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934. Contact: NASA Access Help Desk, (301) 621-0390, fax: (301) 621-0134. However, I'm not sure that this procedure actually worked when we tried it.