Referências Bibliográficas

ABRAMOWITZ, M.; STEGUN, I. A. **Handbook of mathematical functions**. Nova York: Dover Publications, 1965.

AGA 3.1: Natural gas fluids measurement: Concentric, square-edged orifice meters: General equations and uncertainty guidelines. American Gas Association, 1993.

AGA 3.2: Natural gas fluids measurement: Concentric, square-edged orifice meters: Specification and installation requirements. American Gas Association, 2000.

AGA 7: Measurement of gas by turbine meters. American Gas Association, 1996.

AGA 9: Measurement of gas by multipath ultrasonic meters. American Gas Association, 2007.

AGA 10: Speed of sound in natural gas and other related hydrocarbon gases. 2 sd. American Gas Association, 2003.

AGA M-96-2-3: Ultrasonic Flow Measurement for Natural Gas Applications, American Gas Association: Engineering Technical Note, 1996.

ANSI/ASME MFC-2M: Measurement uncertainty for fluid flow in closed conduits. American Society of Mechanical Engineers, 1983.

ANSYS, CFX Release 12.0, ANSYS, 2009.

ANTUNES, B. C., Ultrasonic transit-time on heavy, high viscosity oils, Proceedings of HEAVY OIL WORKSHOP, Rio de Janeiro, 2009.

API 4.8: Proving systems: Operation of proving systems. American Petroleum Institute, Manual of Petroleum Measurement Standards, 2002.

API 5.3: Metering: Measurement of liquid hydrocarbons by turbine meters. American Petroleum Institute, Manual of Petroleum Measurement Standards, 2005.

API 5.8: Metering: measurement of liquid hydrocarbons by ultrasonic flow meters using transit time technology. American Petroleum Institute, Manual of Petroleum Measurement Standards, 2005.

API 12.2.3: Calculation of petroleum quantities using dynamic measurement methods and volumetric correction factors: Proving reports. American Petroleum Institute, Manual of Petroleum Measurement Standards, 2002.

API 13.1: Statistical aspects of measuring and sampling: statistical concepts and procedures in measurements. American Petroleum Institute, Manual of Petroleum Measurement Standards, 2006.

ARANTES, W. F., **Avaliação metrológica da comparação inter-laboratorial da calibração de medidores ultrassônicos**. 2007. Dissertação (Mestrado em Metrologia para Qualidade e Inovação) – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2007.

BOGUE, D.C.; METZNER, A.B. Velocity profiles in turbulent pipe flow – Newtonian and non-Newtonian fluids, **Industrial & Engineering Chemistry Fundamentals** (I&EC Fundamentals), v.2, n.2, 1963.

BRASSIER, P. **Débitmétrie par technique ultrasonore en milieu gazeux industriel**. 2000. Tese (Doutorado) – École Doctorale de Sciences Physiques e de L’Ingenieur, L’Université Bordeaux I, Bordeaux., 2000.

BROWN G.; AUGENSTEIN D.; COUSINS T. Velocity profile effects on multipath ultrasonic meters. Proceedings of INTERNATIONAL SYMPOSIUM ON FLUID FLOW MEASUREMENT, 6., Querétaro, 2006a.

BROWN, G.; AUGENSTEIN, D.; COUSINS, T. The relative merits of ultrasonic meters employing between two and eight paths. Proceedings of INTERNATIONAL SOUTH EAST HYDROCARBON FLOW MEASUREMENT WORKSHOP, 5., Kuala Lumpur, 2006b.

BROWN, G. J.; COUSINS T., AUGENSTEIN, D. R., ESTRADA, H. The performance of ultrasonic meters in heavy oil applications, Proceedings of HEAVY OIL WORKSHOP, Rio de Janeiro, 2009.

BUTKUS, J.; JAKEVICIUS, L.; VLADISAUKAS, A. Control of directivity patterns of electroacoustical transducers when measuring gas flow parameters, **Ultragarsas**, Kaunas, v. 52, p. 13-17, 2004.

CALDON. LEFM 240C: Installation, Operation and Maintenance Manual, 2005.

CALOGIROU, A.; BOEKHOVEN, J.; HENKES, R.A.W.M. Effect of wall roughness changes on ultrasonic gas flowmeters, **Flow Measurement and Instrumentation**, v.12, pp. 219-229, 2001.

DIAS, J. L. **Metodologia para avaliação metrológica e determinação da periodicidade de calibração em sistemas de medição fiscal e apropriação de gás**. 2007. 110p. Dissertação (Mestrado em Metrologia para Qualidade e Inovação) – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2007.

ESTRADA, H.; COUSINS, T.; AUGENSTEIN, D. Installation effects and diagnostic interpretation using the Caldon ultrasonic meter. Proceedings of NORTH SEA FLOW MEASUREMENT WORKSHOP, 22., St. Andrews, 2004. p. 1-14.

FERREIRA, A. L. A. S.; ORLANDO, A. F. Influence of the entrance flow field on the development of the velocity profile in a straight pipe flow. Anais do INTERNATIONAL CONGRESS OF MECHANICAL ENGINEER, 20., Gramado, 2009.

FRASIER, W. E. **Applications for ultrasonic meters**. Pipeline and Gas Technology. 2008.

FOX, R. W.; MCDONALD, A. T. **Introdução à Mecânica dos Fluidos**. 5. ed. Livros Técnicos e Científicos Editora, 2001.

GRIMLEY, T. A. Ultrasonic meter installation configuration testing. Proceedings of AGA 2000 OPERATIONS CONFERENCE, Denver, 2000.

HINZE, J. O. **Turbulence**, McGraw-Hill Publishing Co., New York, 1975.

HOGENDOORN, J.; TAWACKOLIAN, K.; BRAKEL, P.; KLOOSTER, J.; DRENTHEN, J. High viscosity hydrocarbon flow measurement, a challenge for ultrasonic flow meters?. Proceedings of HEAVY OIL WORKSHOP, Rio de Janeiro, 2009.

INMETRO. **GUIA**: Guia para a expressão da incerteza de medição. 3. ed. 2003.

INMETRO. **EA-4/02**: Expressão da incerteza de medição na calibração. 2010.

INMETRO. **VIM**: Vocabulário internacional de metrologia: conceitos fundamentais e gerais e termos associados. 2009.

ISO 3534-2: Statistics: Vocabulary and symbols: Applied statistics. International Organization for Standardization, 2006.

ISO 5168: Measurement of fluid flow: procedures for the evaluation of uncertainties. International Organization for Standardization, 2005.

ISO 12765: Measurement of fluid flow in closed conduits: methods using transit-time ultrasonic flowmeters. International Organization for Standardization, Technical Report, 1998.

ISO **ISO/GUM:** Uncertainty of measurement: guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3). International Organization for Standardization, 2008.

ISO **ISO/VIM:** International vocabulary of metrology: basic and general concepts and associated terms (ISO/IEC Guide 99). International Organization for Standardization, 2007.

JEANNEAY, H.; PIGUET, M. Pipe flow modeling for ultrasonic flow measurement. Proceedings of FLOMEKO, Salvador, 2000.

JUNG, J.C., SEONG, P.H. Estimation of the flow profile correction factor of a transit-time ultrasonic flow meter for the feedwater flow measurement in a nuclear power plant. **IEEE Transactions on nuclear science**, vol.52, n.3, jun. 2005.

KAYS, W. M.; CRAWFORD, M. E. **Convective heat and mass transfer**, Hightstown, NJ: McGraw-Hill, 1993.

KROHNE. UFM 3030 Technical Data Sheet, Krohne, 2005.

LANSING, J. Ultrasonic gas flowmeter diagnostic basics. **Pipeline & Gas Journal**, 2001.

LAUNDER, B.E.; SPALDING, D.B. **The numerical computation of turbulent flows**. Computer methods in applied mechanics and engineering, **3**: p. 269-289, 1974.

MARCHETTI, C., **Utilização de medidores ultrassônicos para medição fiscal de vazão de gás natural**. 2009. Dissertação (Mestrado em Metrologia para Qualidade e Inovação) – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2009.

MATTINGLY, G. E.;YEH, T. T. **NIST's ultrasonic technology assessment program to improve flow measurement**. NIST Tech. Note Virgínia: NIST, 1999.

MOORE, P. I. **Modelling of installation effects on transit time ultrasonic flow meters in circular pipes**. 2000. Tese (Doutorado) – Departament of Electronic and Electrical Engineering, University of Strathclyde, Grã-Bretanha, 2000.

MOORE, P. I.; BROWN, G. J.; STIMPSON, B. P. Modelling of transit time ultrasonic flowmeters in theoretical asymmetric flow. Proceedings of FLOMEKO, Salvador, 2000a.

MOORE, P. I.; BROWN, G. J.; STIMPSON, B. P. Ultrasonic transit-time flowmeters modeled with theoretical velocity profiles: methodology. **Measurement Science and Technology**. Bristol, UK, v. 11, n. 11, 2000b.

MOORE, P; PIOMELLI, U.; JOHNSON, A. N.; ESPINA, P. I. Simulations of ultrasonic transit time in a fully developed turbulent flow using a ray-tracing method. Proceedings of NORTH SEA FLOW MEASUREMENT WORKSHOP, 20., St. Andrews, 2002.

MYLVAGANAM, K. S. High-rangeability ultrasonic gas flowmeter for monitoring flare gas. **IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control**, Aurora, v. 36, n. 2, 1989.

NEL, **Long term evaluation of ultrasonic flowmeter**. Flow Measurement Guidance Note n. 25, Glasgow. 2000.

OBERKAMPF, W. L., TRUCANO, T. G., Verification and validation in computational fluid dynamics. **Progress in Aerospace Sciences Journal**, 2002. ref. SAND2002-0529.

OIML R-117-1: Measuring systems for liquids other than water: metrological and technical requirements. International Organization of Legal Metrology, 2007.

OIML R-137-1: Gas Meters: Requirements. International Organization of Legal Metrology, 2006.

OLIVEIRA, T. B. V.; PINHEIRO, J. A.; MATA, J. D.; CHURRO, J. J. T.; ORLANDO, A. F.; VAL, L. G. Medição de petróleo e diagnóstico em medidores do tipo ultra-sônico em elevadas vazões e viscosidades, Anais do RIO PIPELINE CONFERENCE, 2007.

ORLANDO, A.F.; PINHEIRO, J. A.; MATA, J. D. Heavy oil flow measurement and diagnostics with ultrasonic flow meters. Proceedings of HEAVY OIL WORKSHOP, Rio de Janeiro, 2009.

RTM-001/2000: Regulamento técnico metrológico de petróleo e gás natural. ANP/INMETRO, 2000.

RTM-64: Regulamento técnico metrológico referente à medição dinâmica de petróleo, derivados líquidos e álcool. INMETRO, 2003.

SAKARIASSEN, R.; SDUN, W.; VULOVIC, F.; VIETH, D. Long term comparison of an ultrasonic meter and a turbine meter with an orifice meter at EMS test loop. Proceedings of NORTH SEA FLOW MEASUREMENT WORKSHOP, 18., St. Andrews, 2000.

SALAMI, L. A. Application of a computer to asymmetric flow measurement in circular pipes. **Transaction of Institute Measurement and Control**, London, v. 6, n. 4, p. 197-206, 1984.

SAVIDGE, J. L. AGA10 sound speed equations: background, thermodynamic relations, ideal gas and equation of state methods, uncertainty analysis, and calculation flow diagram for natural gas measurement applications. Proceedings of INTERNATIONAL SYMPOSIUM ON FLUID FLOW MEASUREMENT, 5., Washington, 2002.

SCHEID F. **Theory and Problems of Numerical Analysis**. Schaum's Outline Series, McGraw-Hill Book Company, 1968.

SCHLICHTING, H. **Boundary-layer theory**. McGraw-Hill Book, 1968.

SILVA, H. A. **Análise metrológica do desempenho de medidores ultrassônicos de vazão de líquidos como diagnóstico de calibração, instalação e operação**.

2008. 100p. Dissertação (Mestrado em Metrologia) – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2008.

VATERLAUS, H. P. A new intelligent ultrasonic flowmeter for closed conduits and open channels. **Waterpower**, p. 999-1008, 1995.

VATERLAUS, H. P.; HOSSLE, T.; GIORDANO, P.; BRUTTIN, C. Ultrasonic flowmeters**.** In: WEBSTER, J. G. **Measurement, Instrumentation and Sensors Handbook**. Flórida: CRC Press & IEEE, 1999. p. 28.74-28.89.

WHITE, F. M. **Fluid mechanics.** New York: McGraw-Hill, 1979.

YAKHOT, V.; ORSZAG, S. A., Renormalization group analysis of turbulence: basic theory. **Journal of Scientific Computing**. **1**(1): p. 3-50, 1986.

YEH, T. T.; MATTINGLY, G. E. Computer simulations of ultrasonic flow meter performance in ideal and non-ideal pipeflows. Proceedings of ASME FLUIDS ENGINEERING DIVISION SUMMER MEETING, Vancouver, 1997. p. 22-26. ref. FEDSM97-3012.

YODER, J. Ultrasonic flow meters in the energy measurement spotlight. **Pipeline & Gas Journal**, 2009.

ZAGAROLA, M.V.; SMITS, A.J. Mean-flow scaling of turbulent pipe flow, **J. Fluid. Mech.**, v.373, pp. 33-79, 1998.

ZANKER, K. J. The effects of Reynolds number, wall roughness, and profile asymmetry on single- and multi- path ultrasonic meters. Proceedings of NORTH SEA FLOW MEASUREMENT WORKSHOP, 17., Noruega, 1999. 117-129.

ZANKER, K. J.; BROWN, G. J. The performance of a multi-path ultrasonic meter with wet gas. Proceedings of NORTH SEA FLOW MEASUREMENT WORKSHOP, 18., St. Andrews, 2000.

ZANKER, K. J. Diagnostic ability of the Daniel four-path ultrasonic flow meter. Proceedings of SOUTH EAST ASIA HYDROCARBON FLOW MEASUREMENT WORKSHOP, 2003.

Apêndice A
Curvas: Velocidade de 0D a 100D

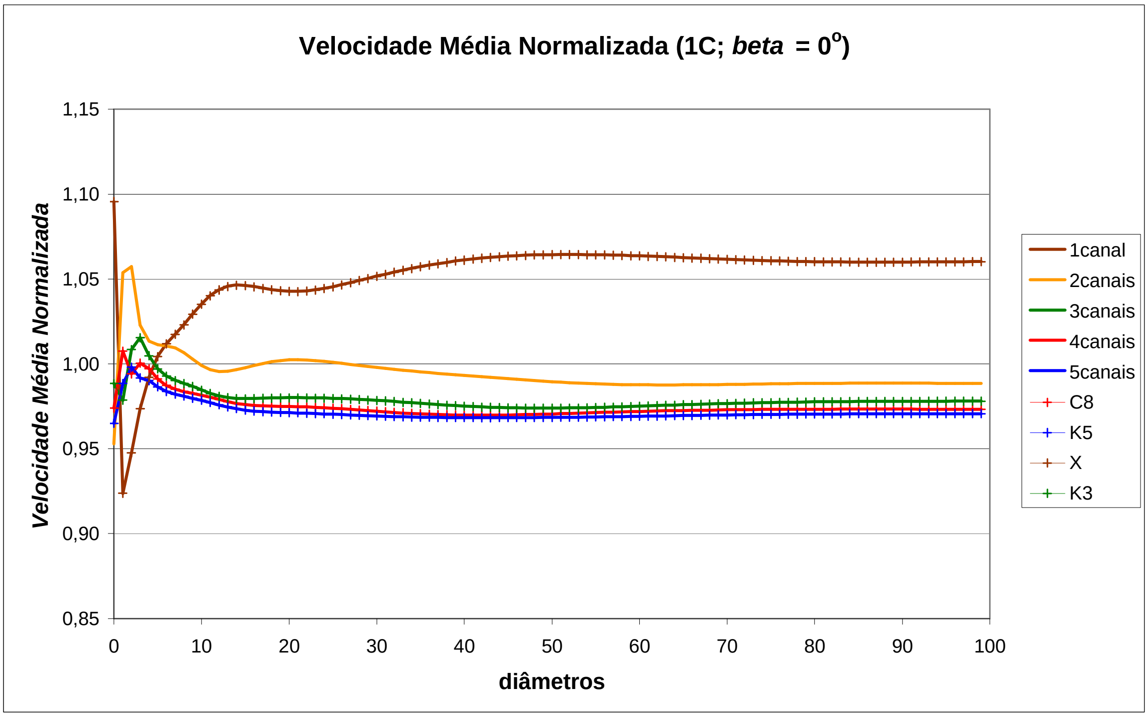

Figura A-1: Velocidade adimensional para β = 0º (1C).

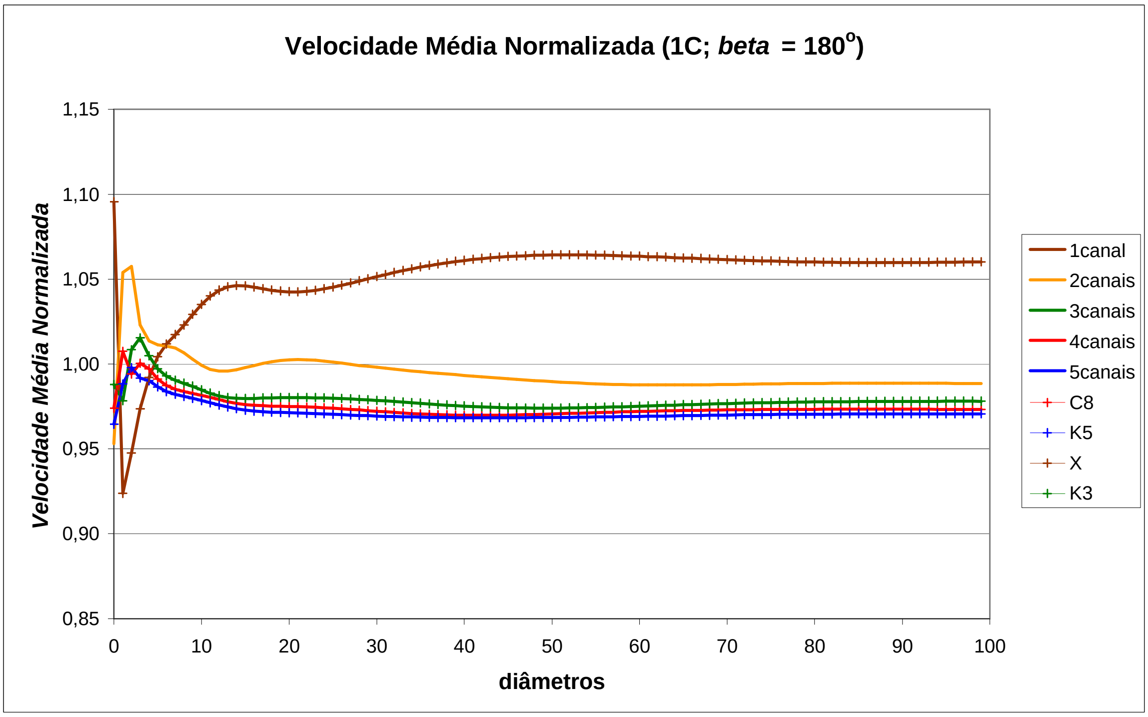

Figura A-2: Velocidade adimensional para β = 180º (1C).

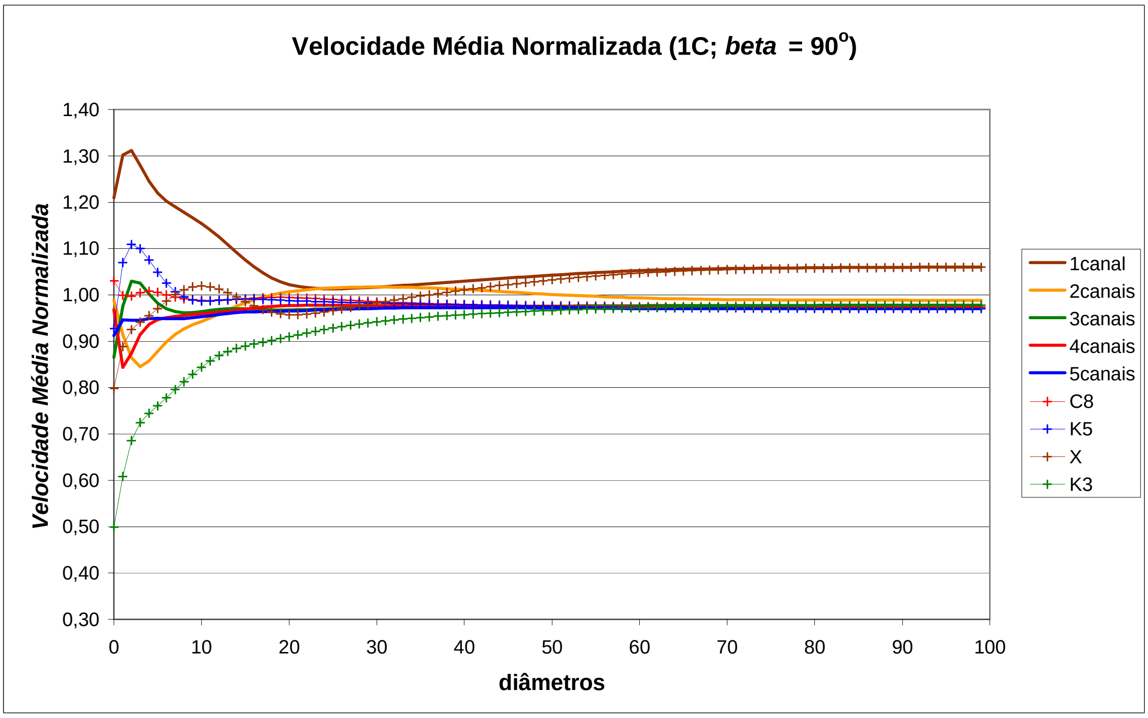

Figura A-3: Velocidade adimensional para $\beta = 90º$ (1C).

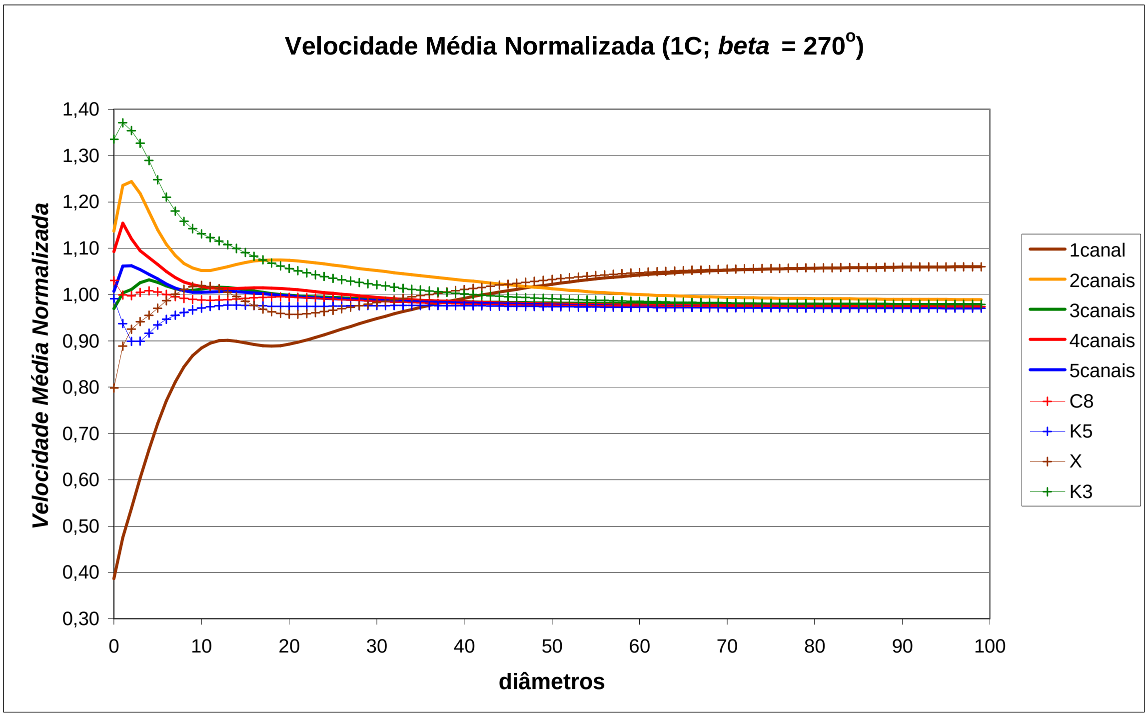

Figura A-4: Velocidade adimensional para $\beta = 270º$ (1C).

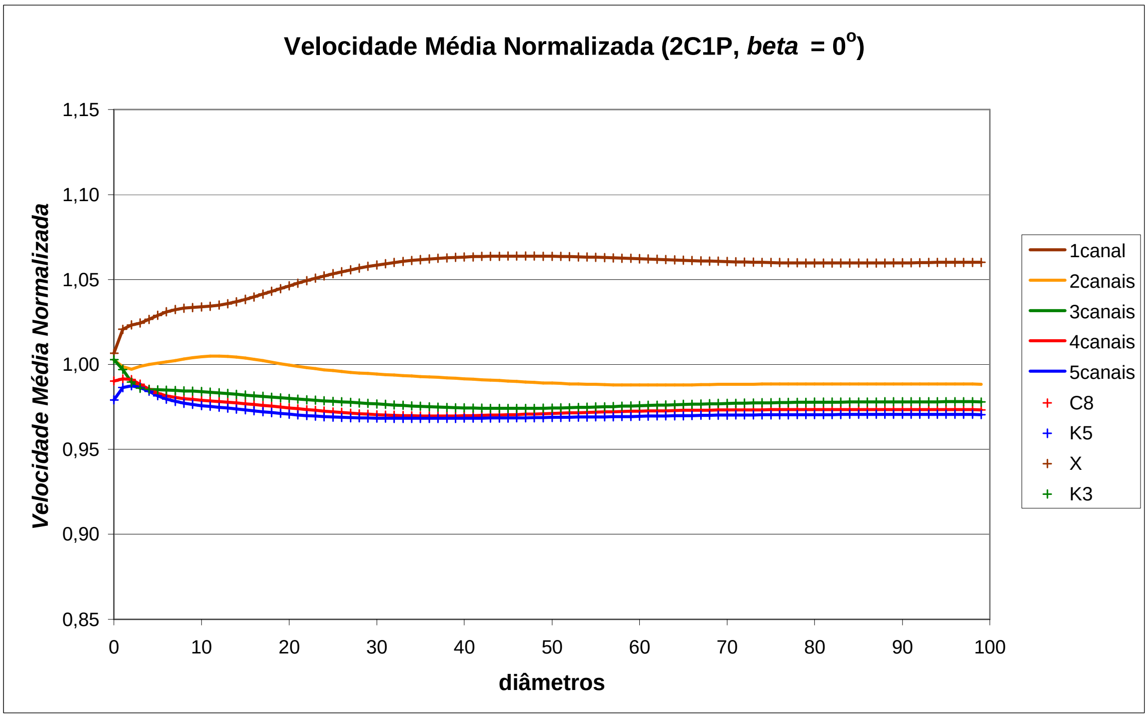

Figura A-5: Velocidade adimensional para β = 0º (2C1P).

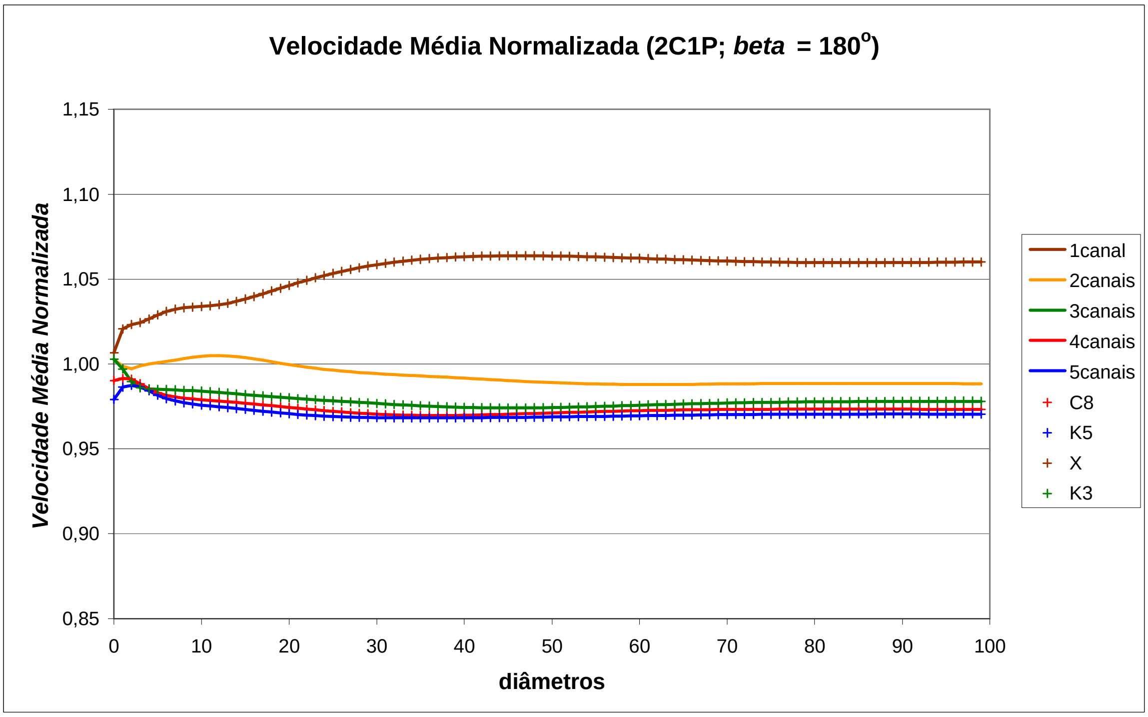

Figura A-6: Velocidade adimensional para β = 180º (2C1P).

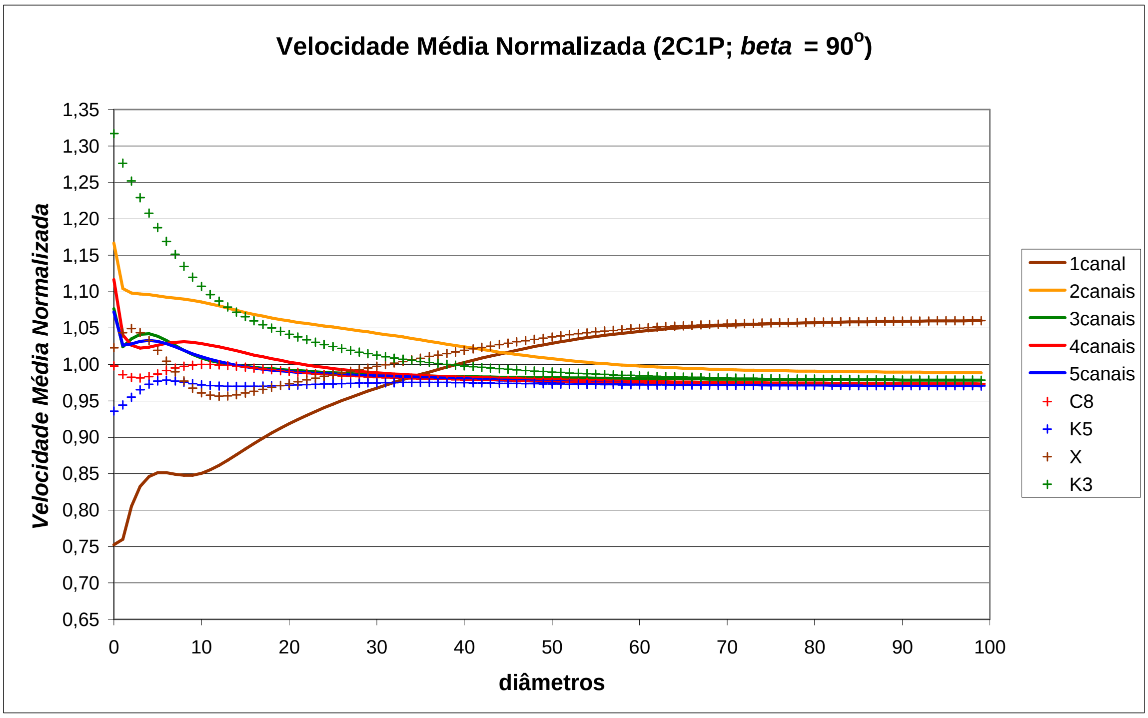

Figura A-7: Velocidade adimensional para $\beta = 90°$ (2C1P).

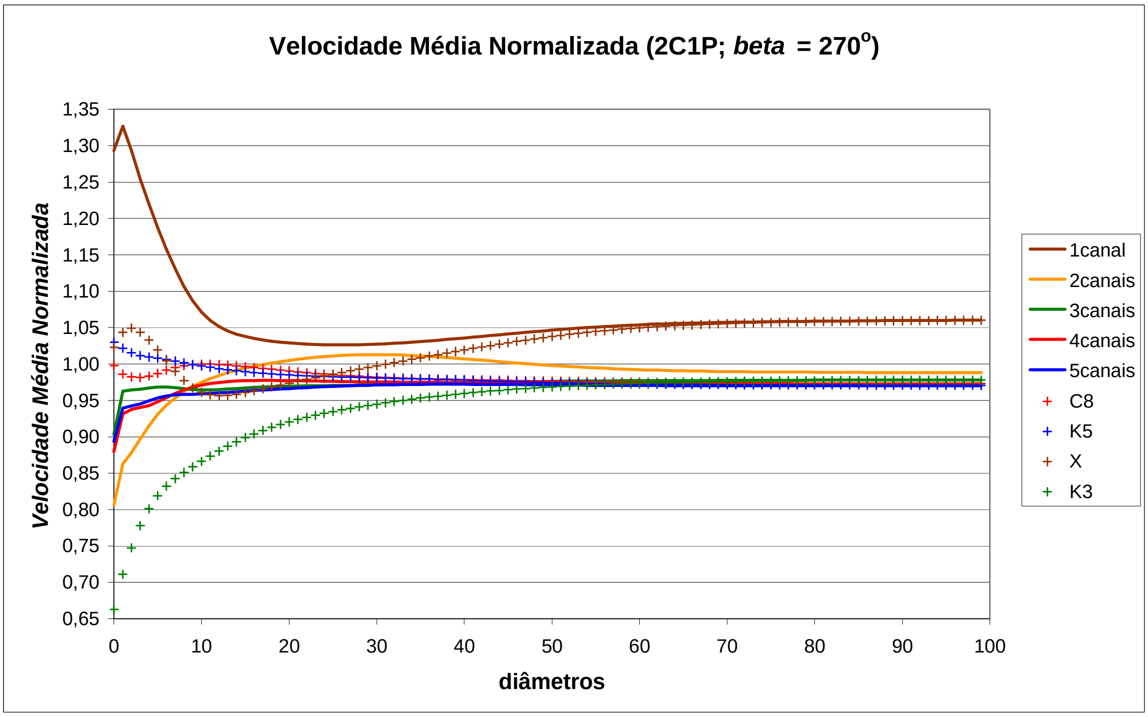

Figura A-8: Velocidade adimensional para $\beta = 270°$ (2C1P).

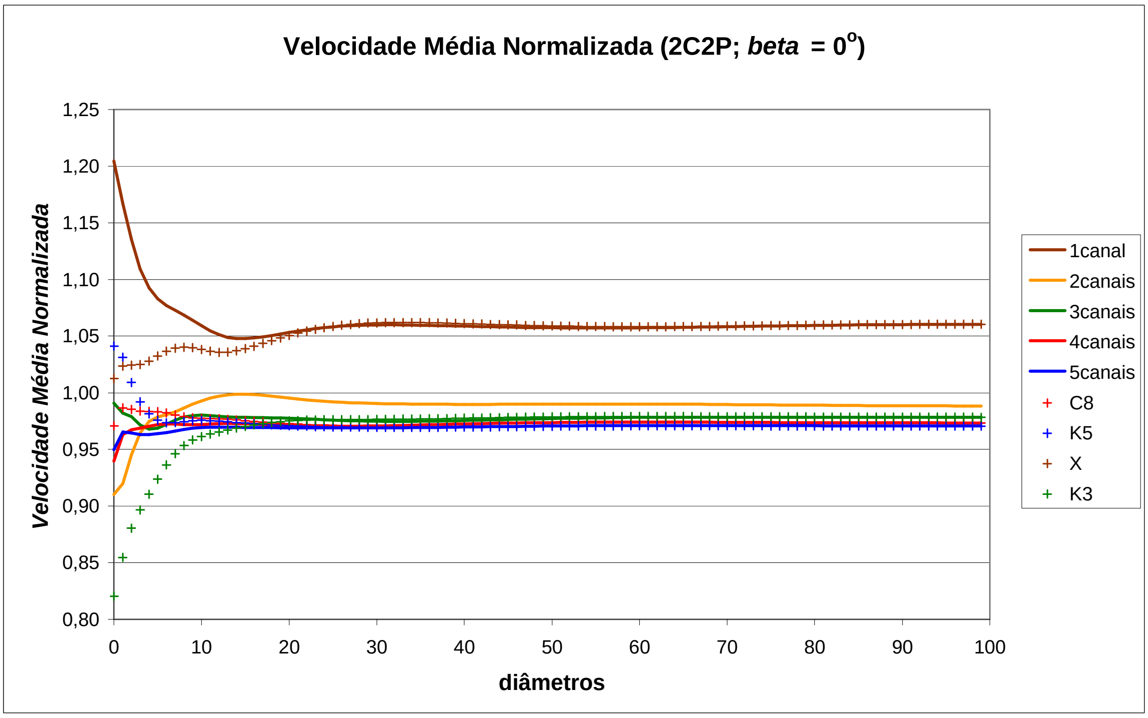

Figura A-9: Velocidade adimensional para $\beta = 0^o$ (2C2P).

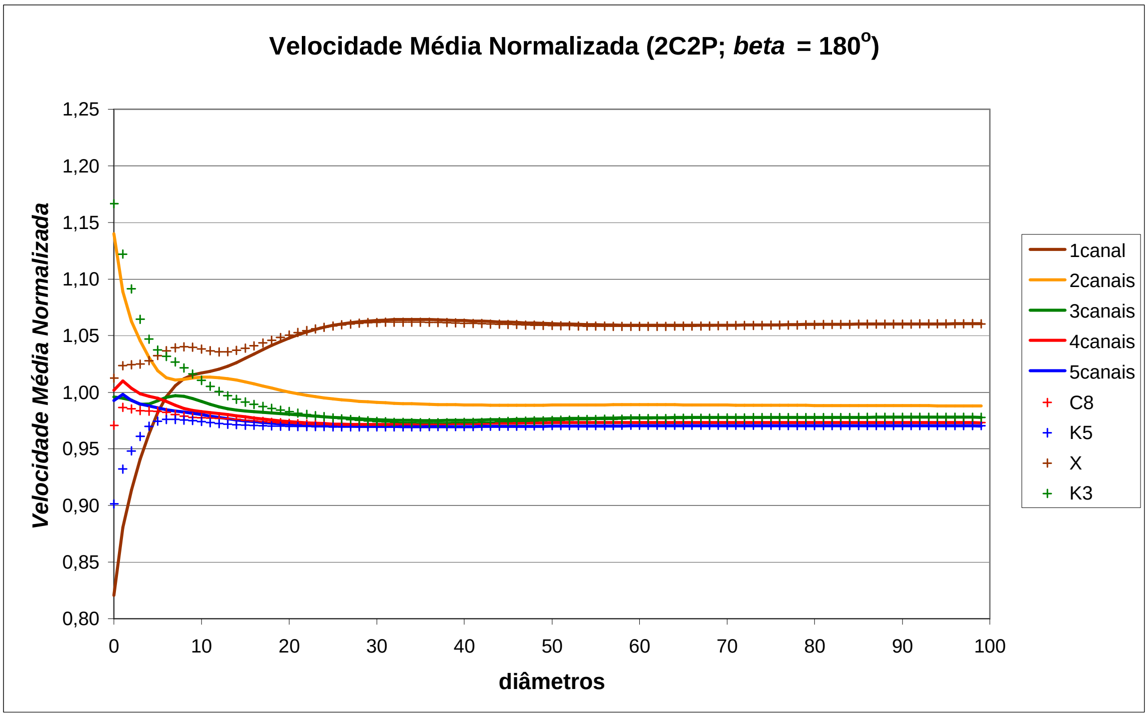

Figura A-10: Velocidade adimensional para $\beta = 180^o$ (2C2P).

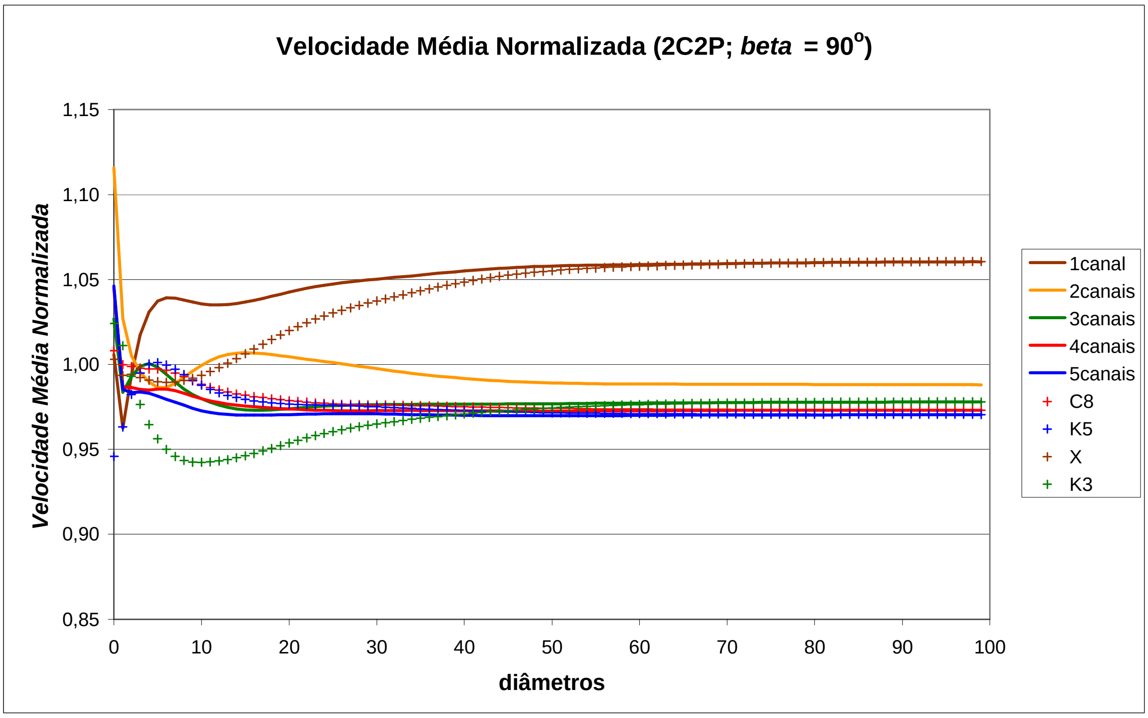

Figura A-11: Velocidade adimensional para β = 90º (2C2P).

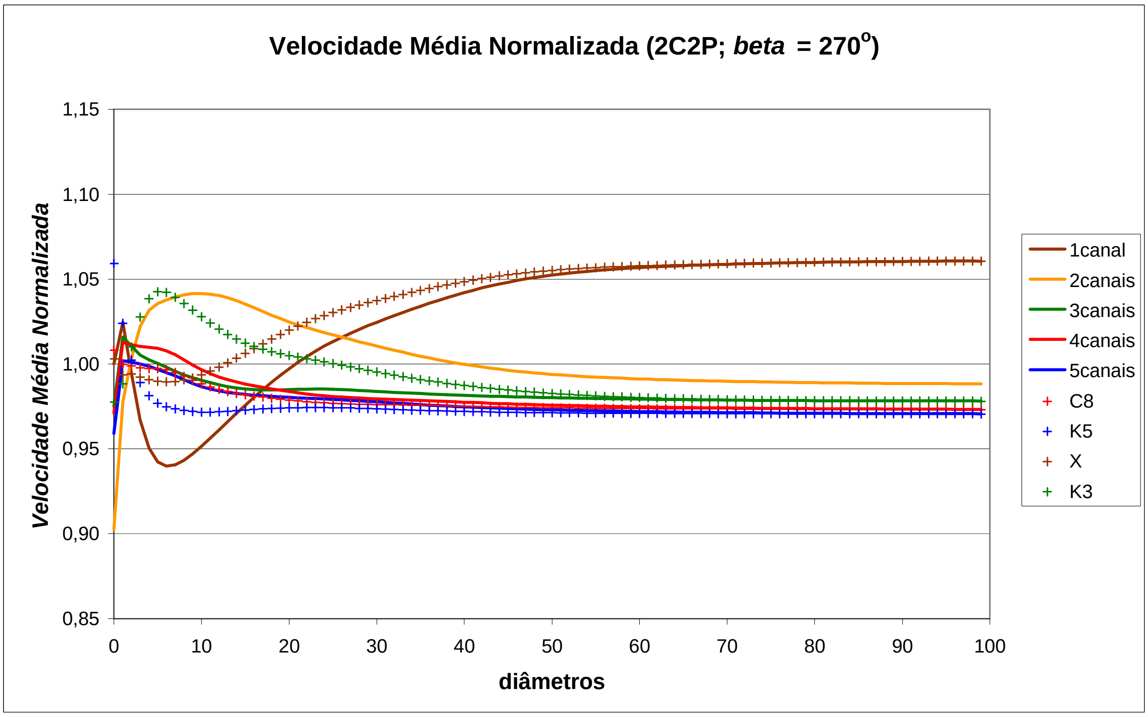

Figura A-12: Velocidade adimensional para β = 270º (2C2P).

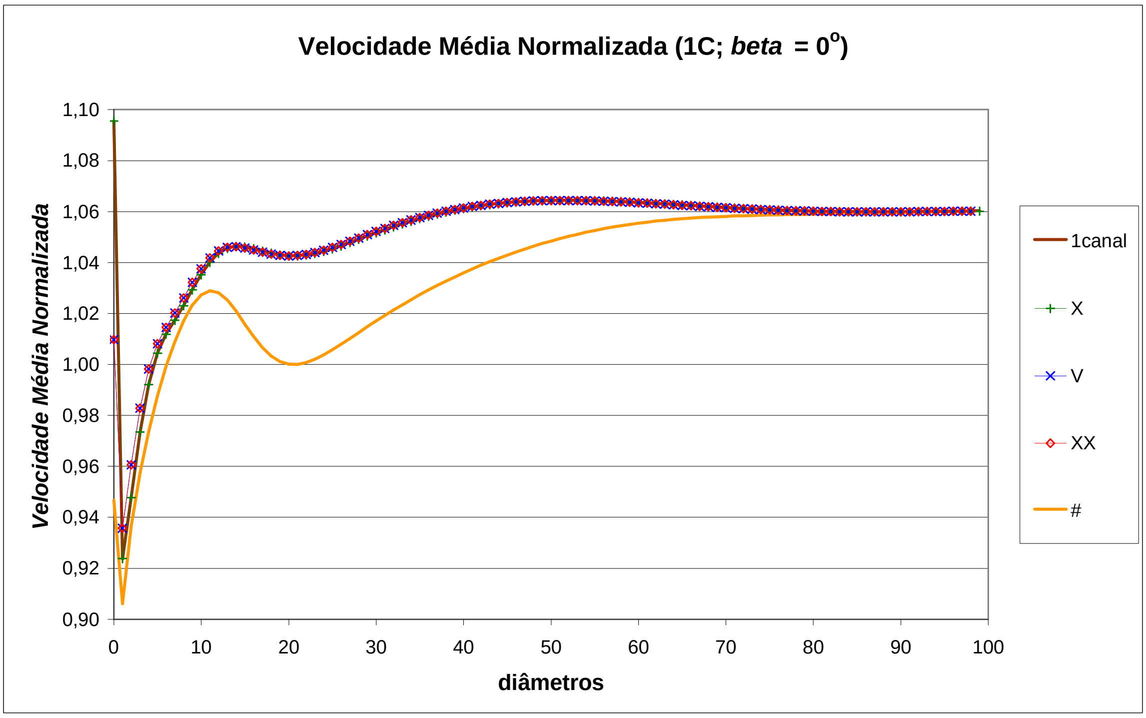

Figura A-13: Velocidade adimensional para $\beta = 0$ (1C).

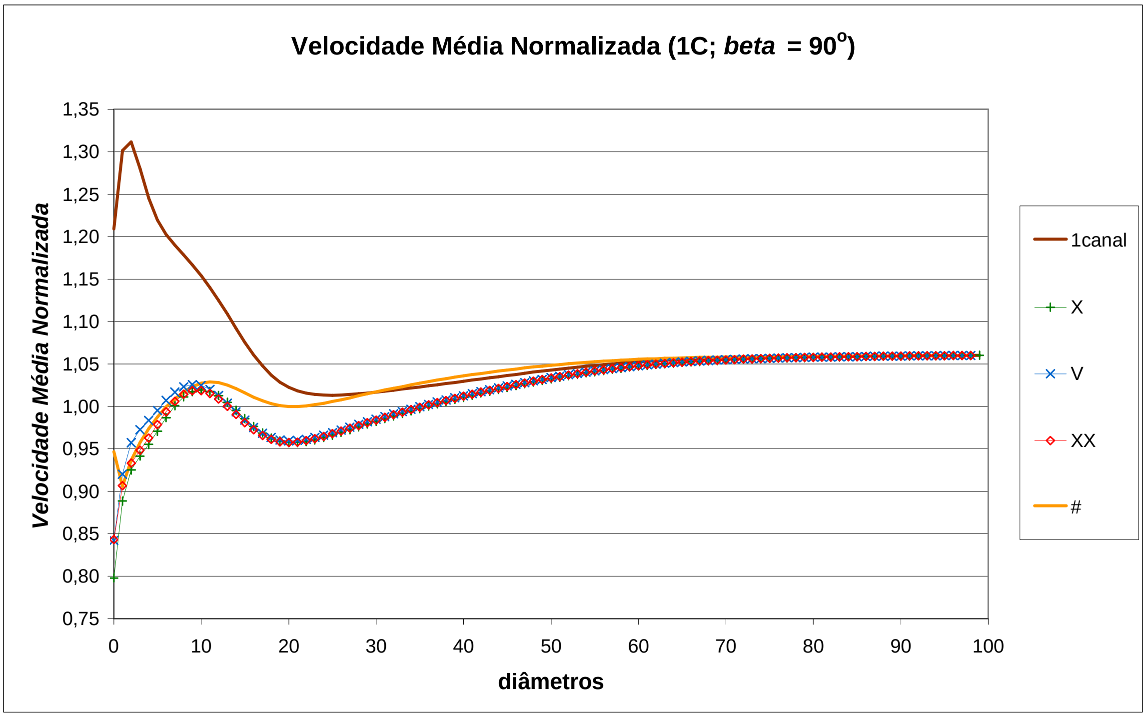

Figura A-14: Velocidade adimensional para $\beta = 90$ (1C).

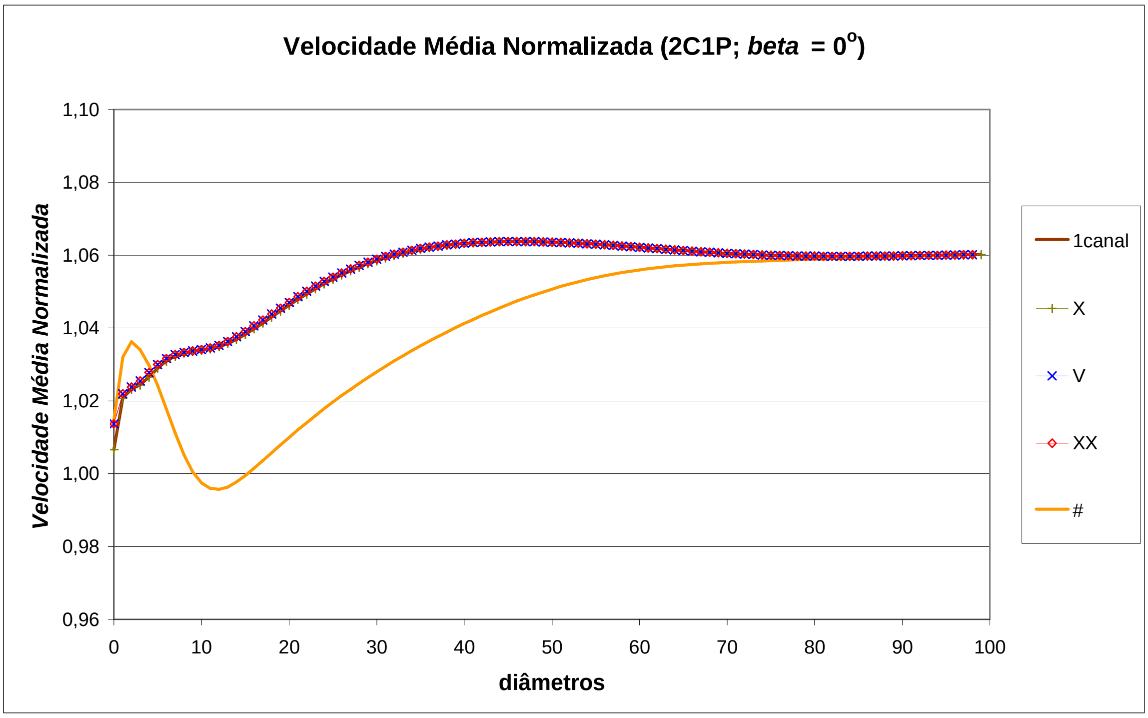

Figura A-15: Velocidade adimensional para $\beta = 0$ (2C1P).

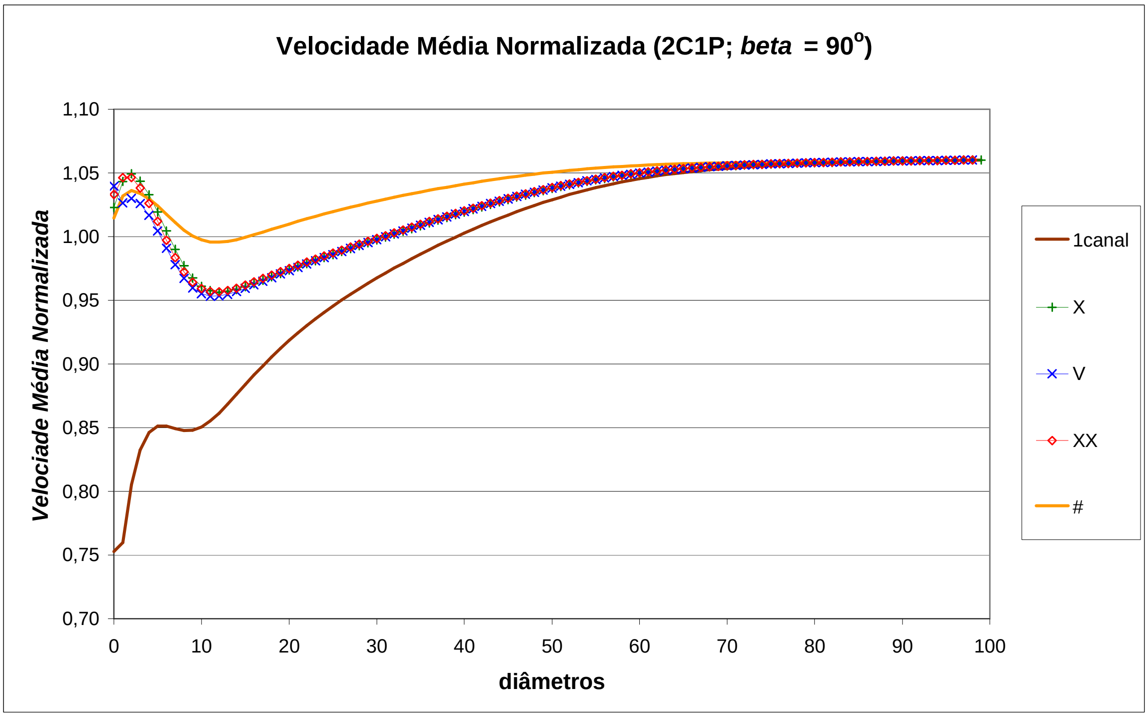

Figura A-16: Velocidade adimensional para $\beta = 90$ (2C1P).

Apêndice B
Curvas: Fator de 0D a 100D.

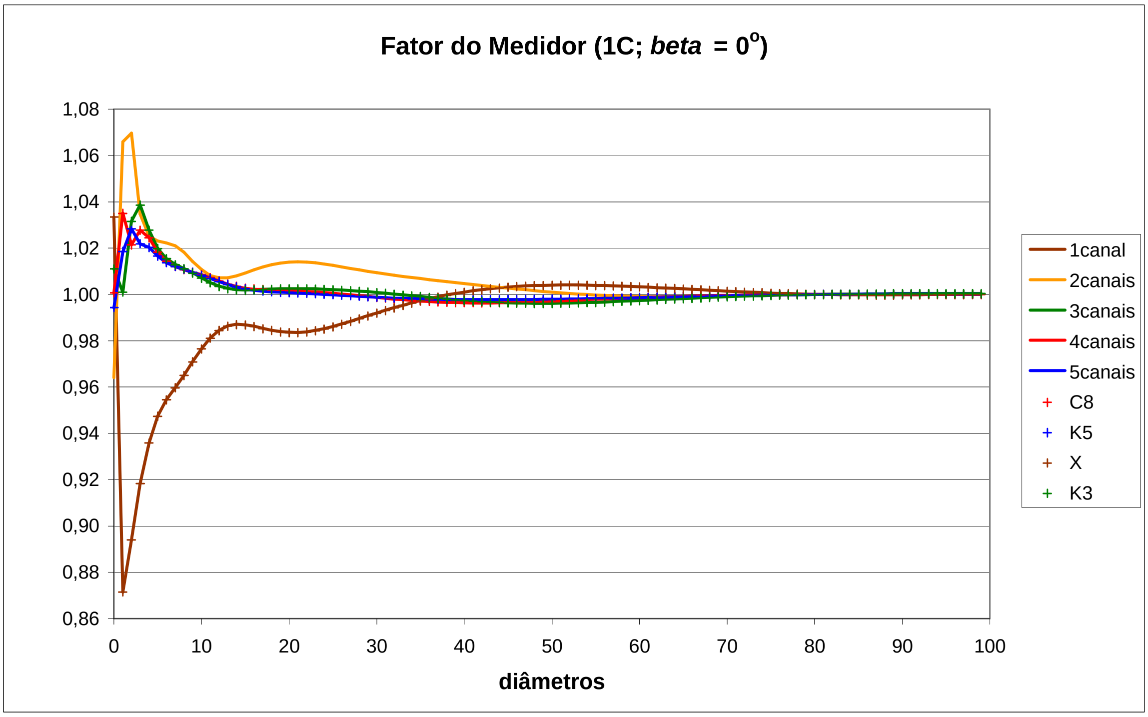

Figura B-1: Fator de velocidade para $\beta = 0°$ (1C).

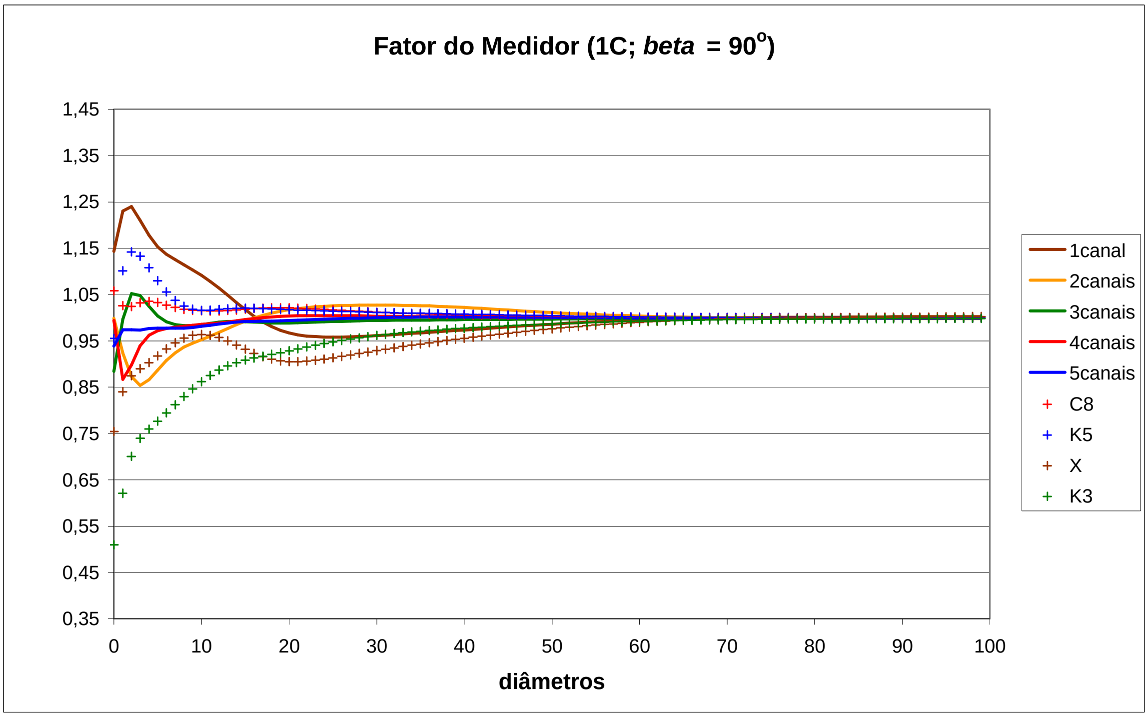

Figura B-2: Fator de velocidade para $\beta = 90°$ (1C).

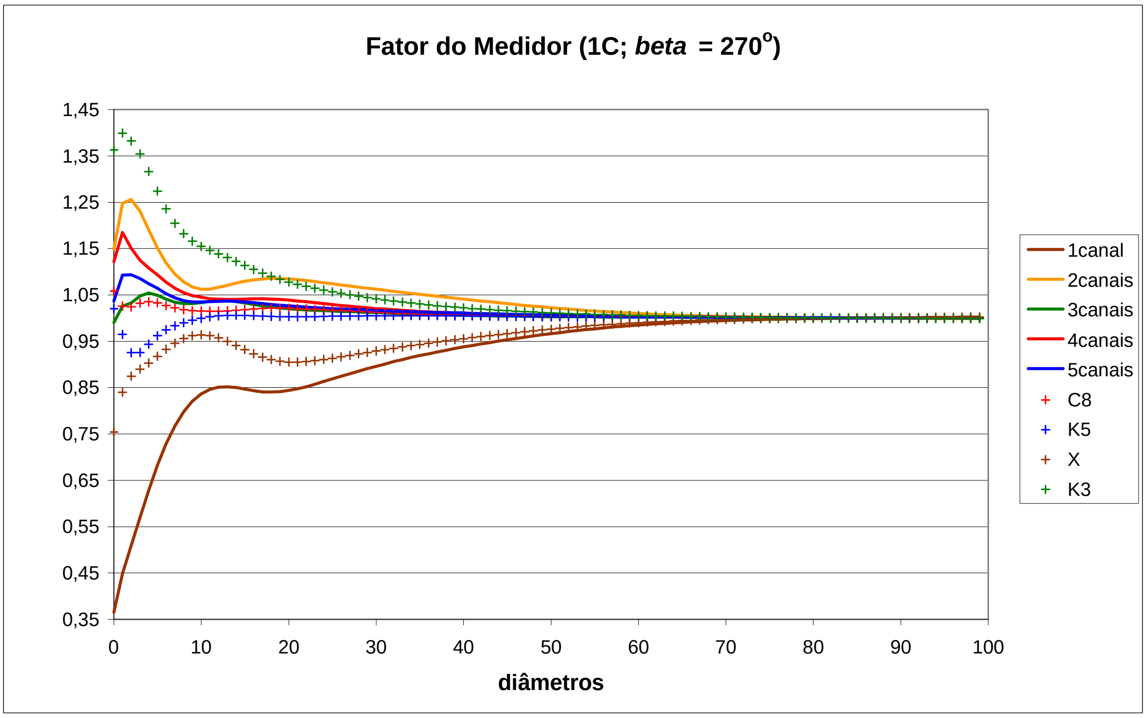

Figura B-3: Fator de velocidade para β = 270º (1C).

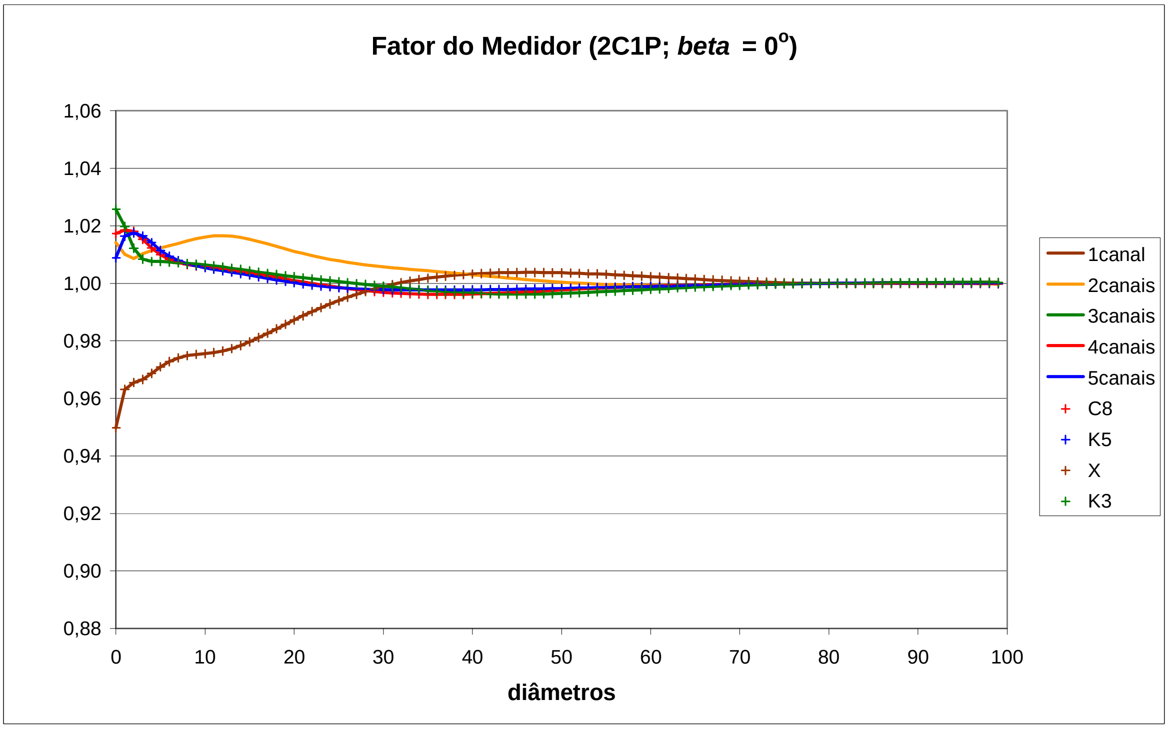

Figura B-4: Fator de velocidade para β = 0º (2C1P).

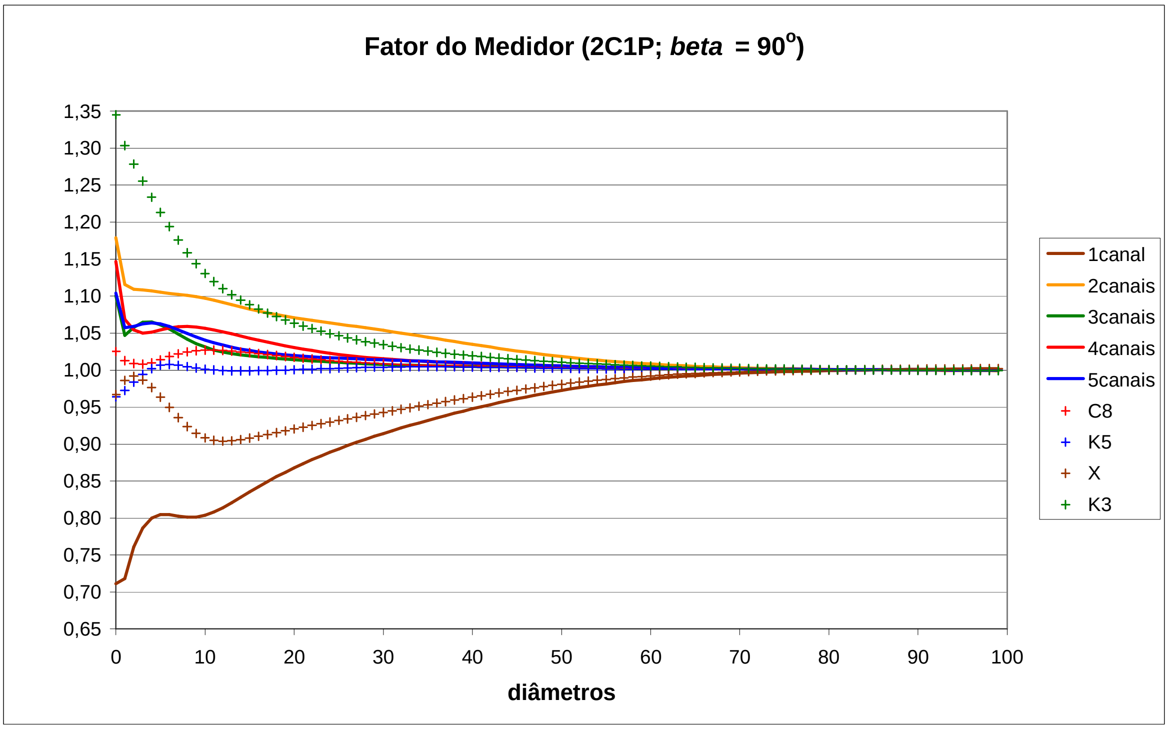

Figura B-5: Fator de velocidade para β = 90º (2C1P).

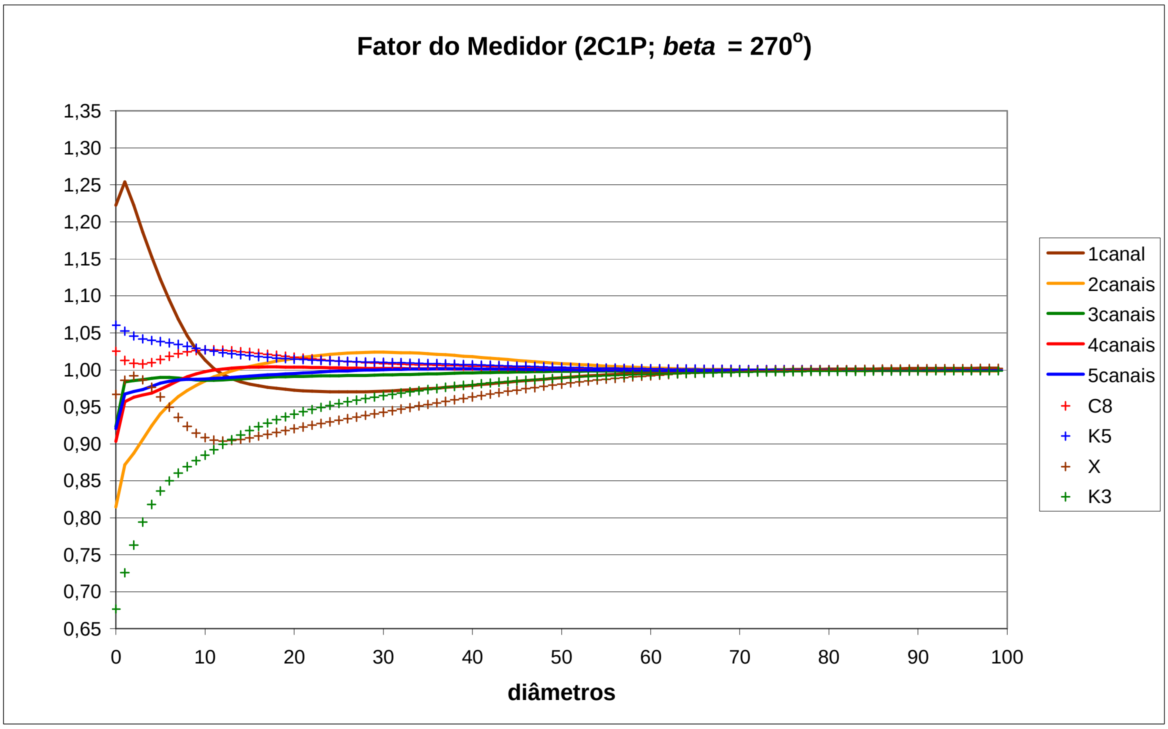

Figura B-6: Fator de velocidade para β = 270º (2C1P).

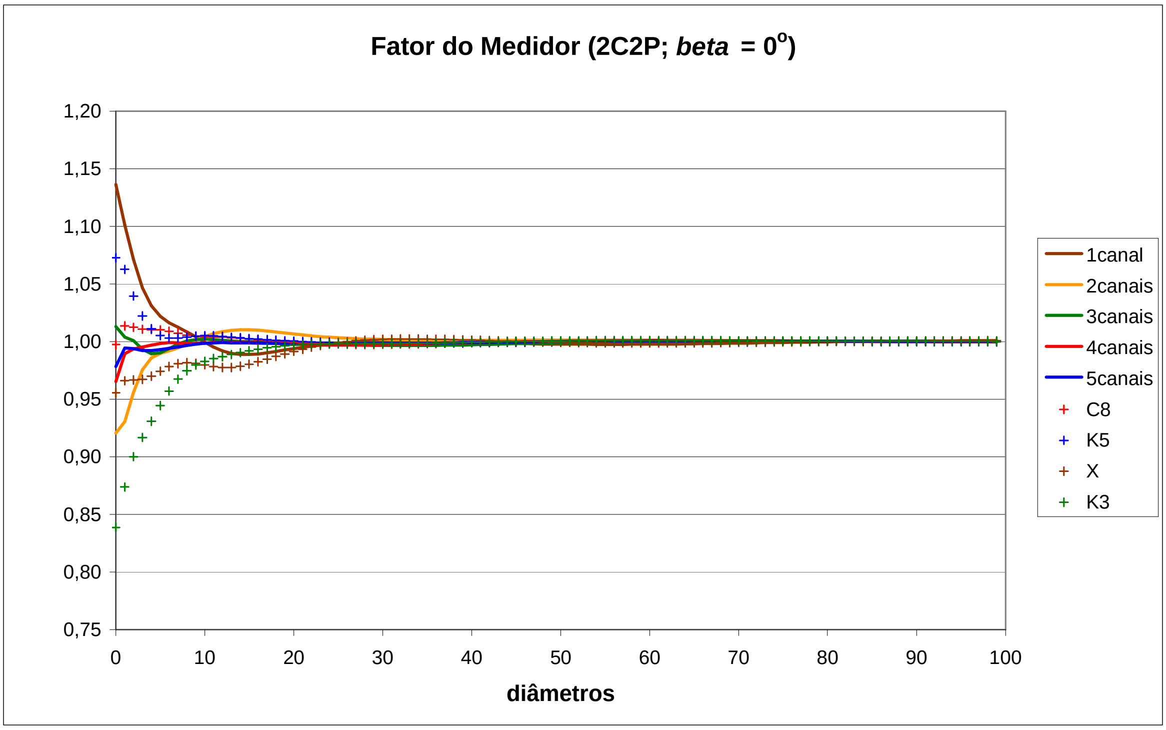

Figura B-7: Fator de velocidade para β = 0º (2C2P).

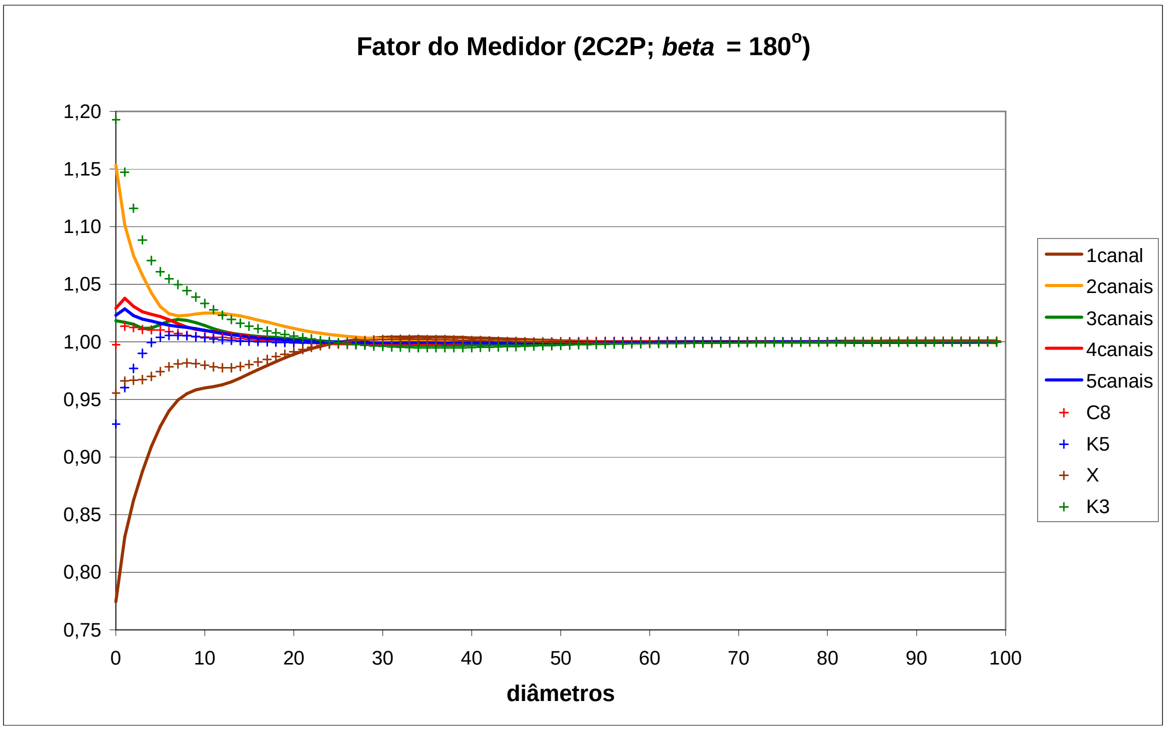

Figura B-8: Fator de velocidade para β = 180º (2C2P).

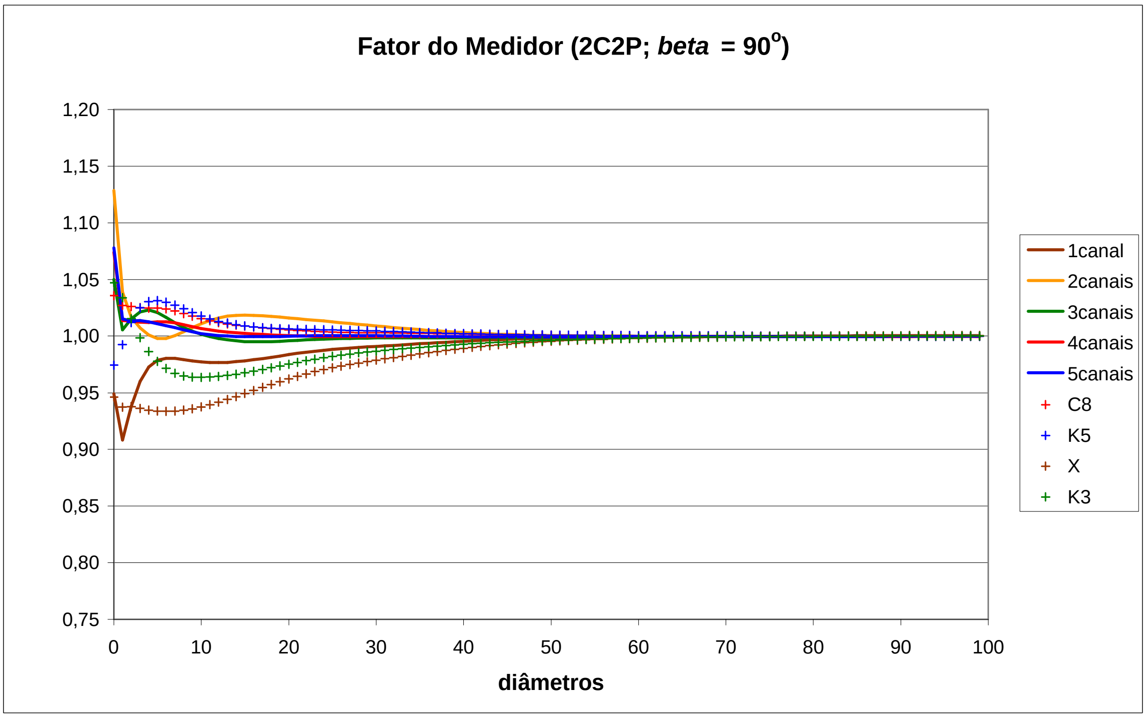

Figura B-9: Fator de velocidade para β = 90º (2C2P).

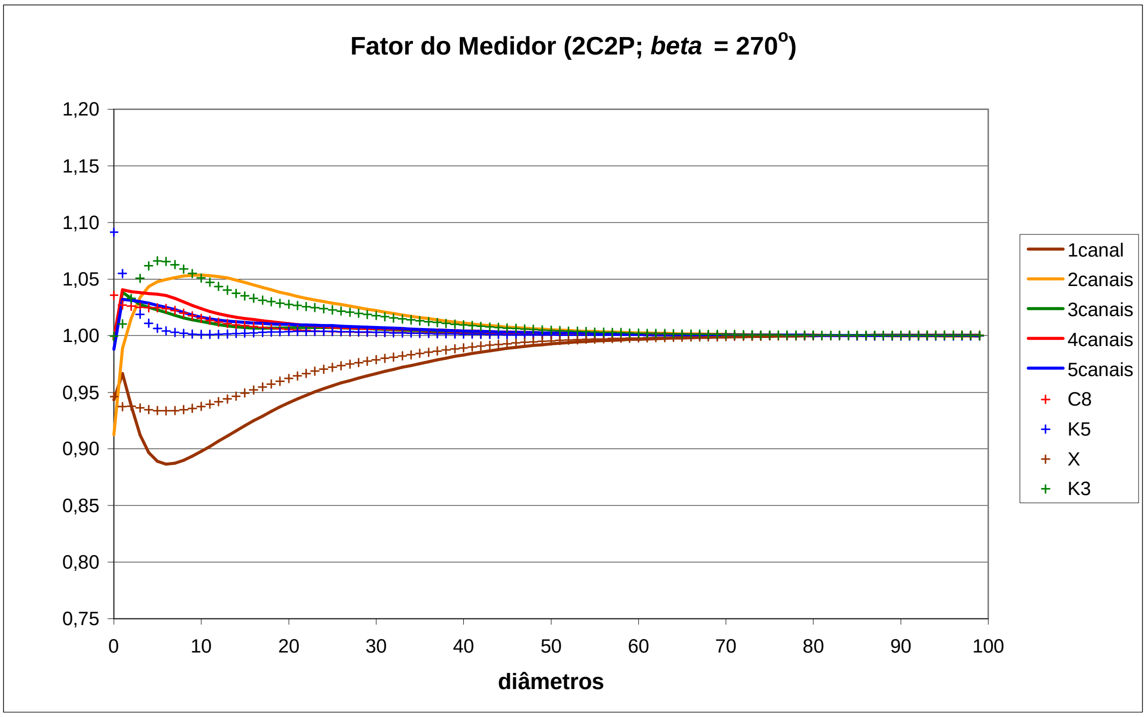

Figura B-10: Fator de velocidade para β = 270º (2C2P).

Apêndice C
Curvas: Velocidade na Seção Transversal

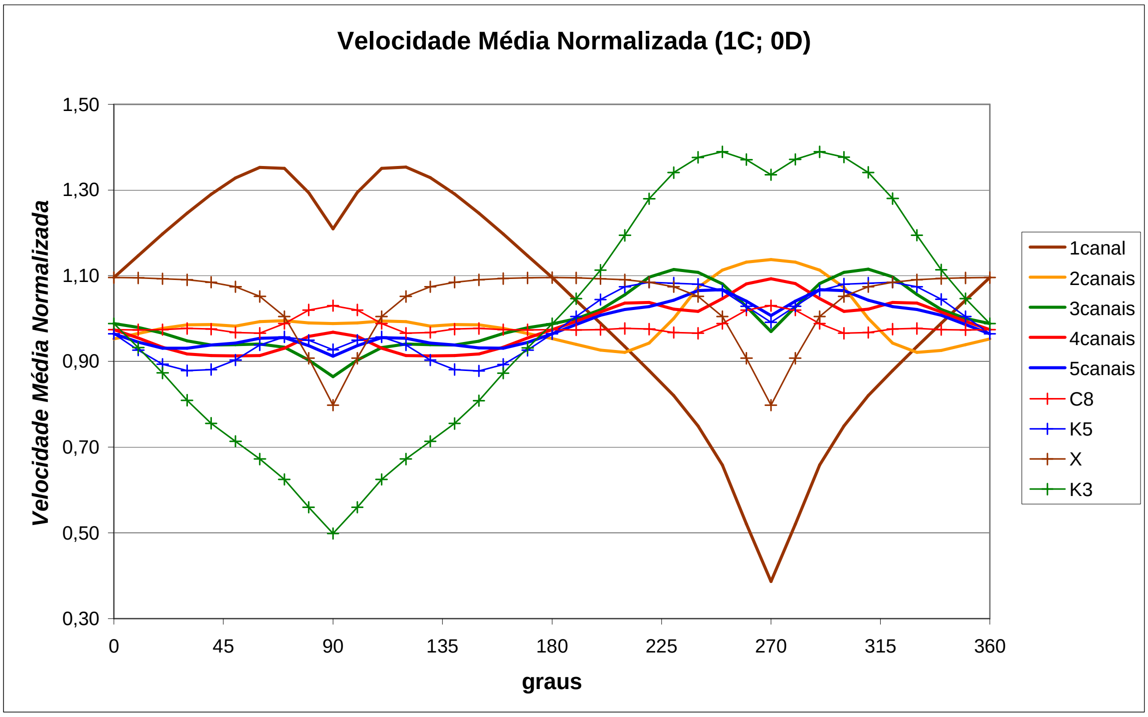

Figura C-1: Velocidade adimensional na seção transversal a 0D (1C).

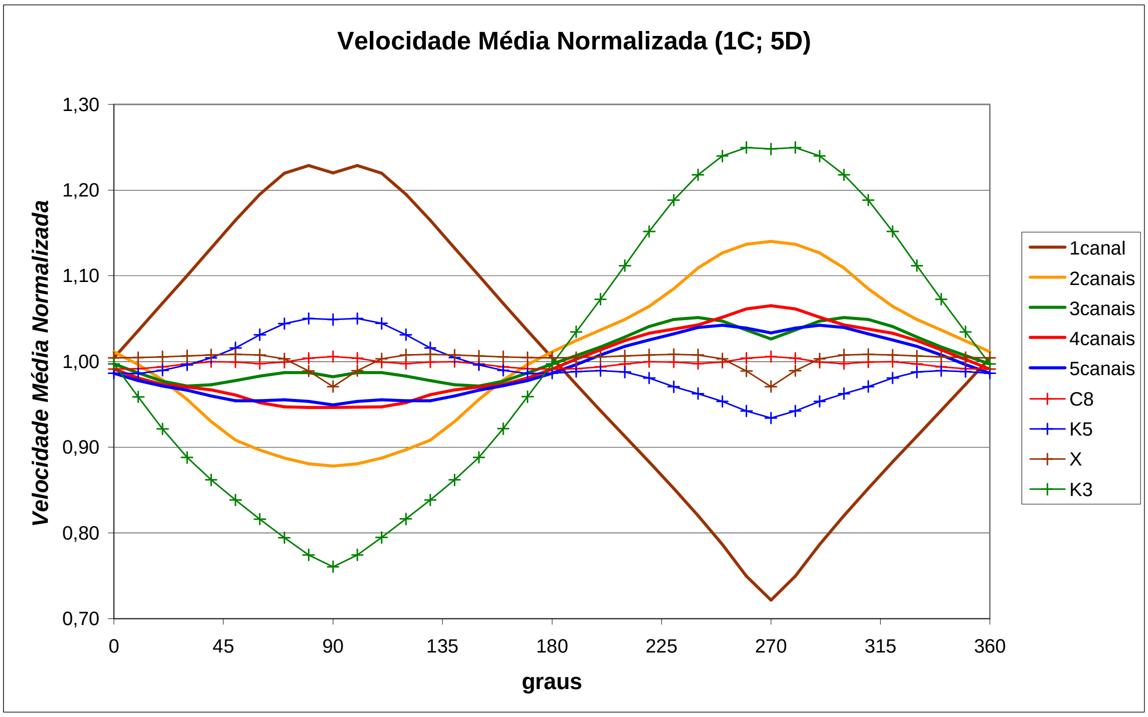

Figura C-2: Velocidade adimensional na seção transversal a 5D (1C).

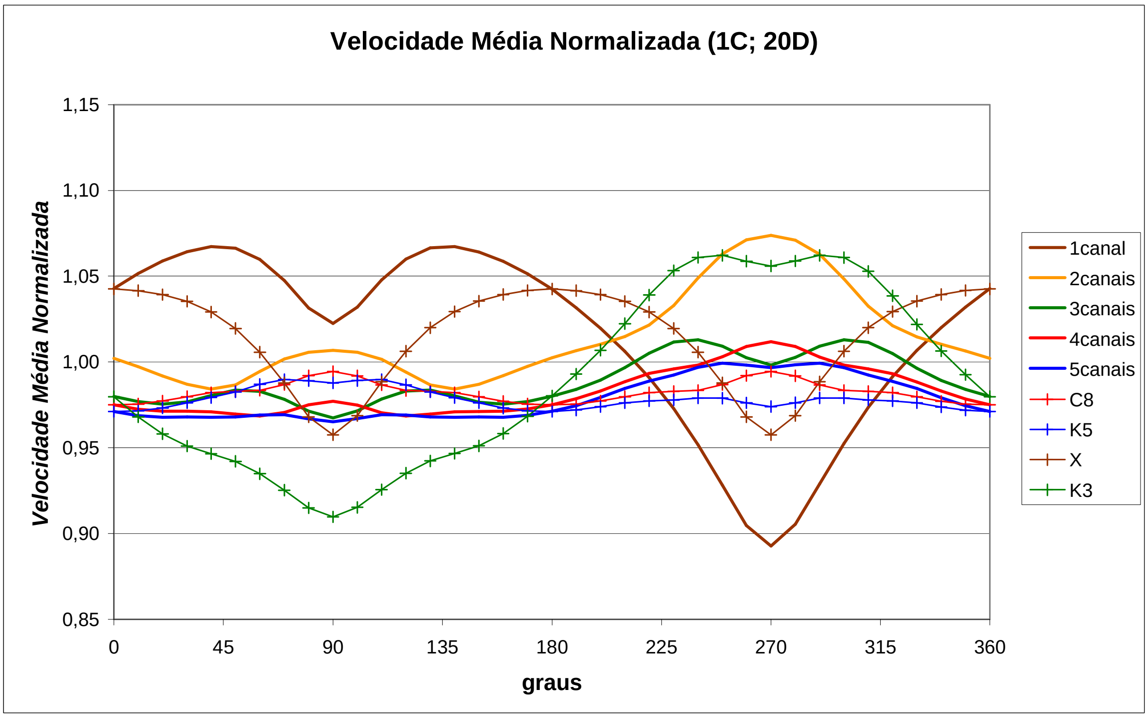

Figura C-3: Velocidade adimensional na seção transversal a 20D (1C).

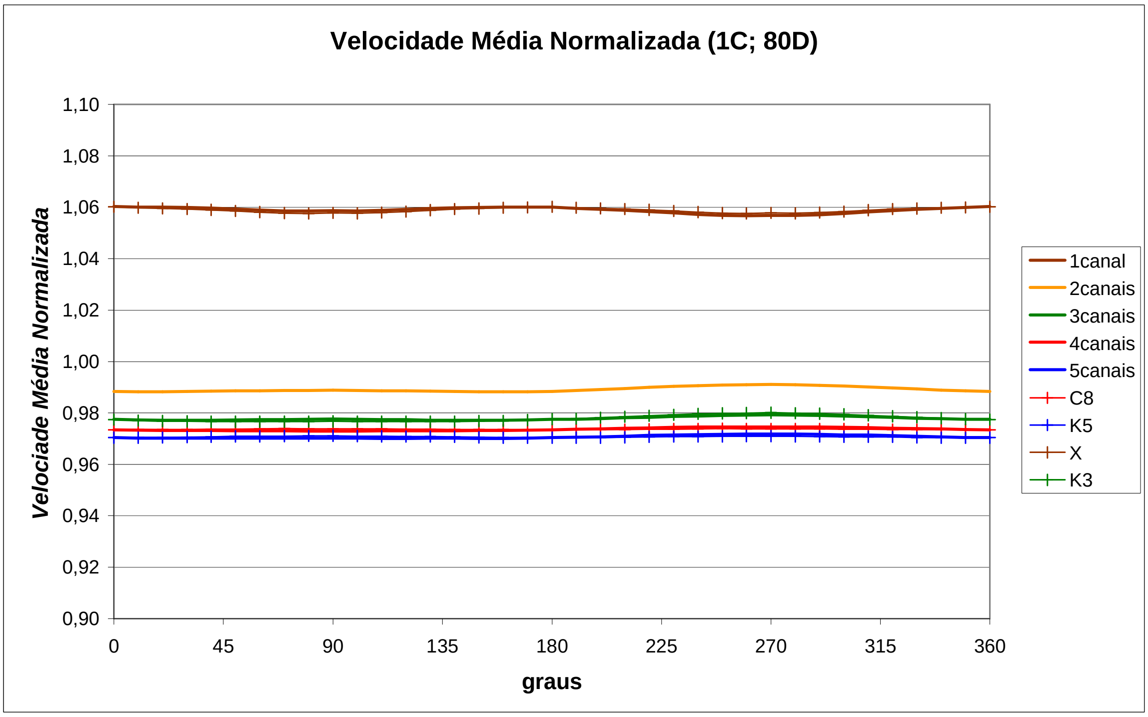

Figura C-4: Velocidade adimensional na seção transversal a 80D (1C).

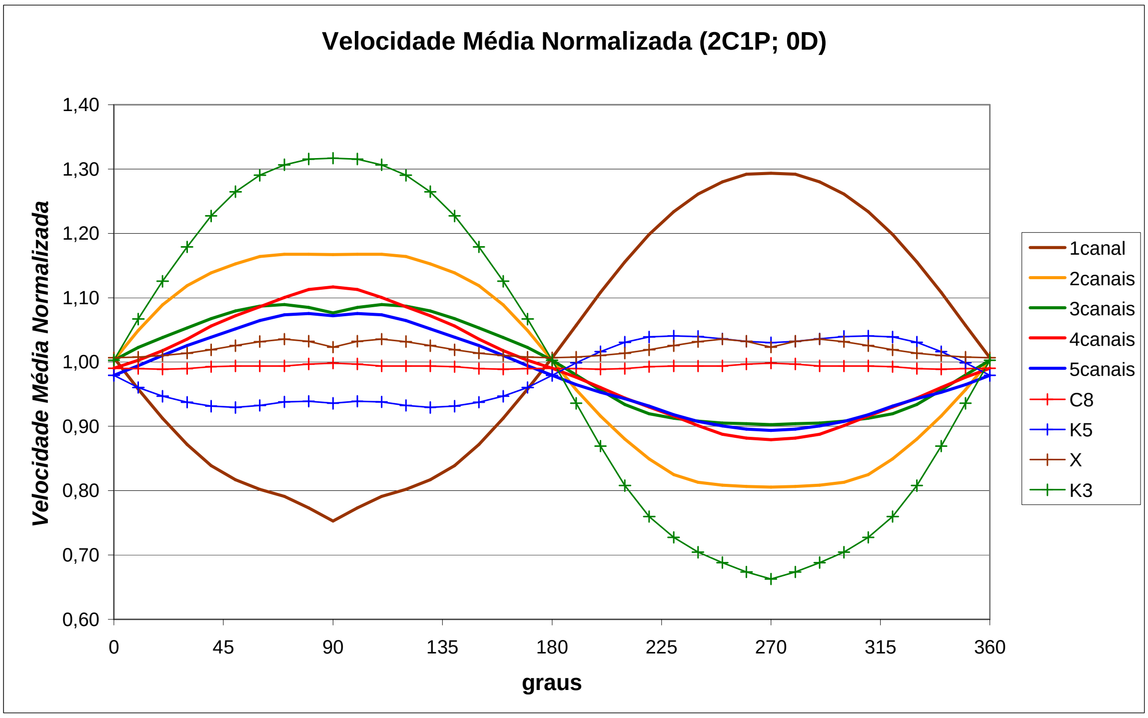

Figura C-5: Velocidade adimensional na seção transversal a 0D (2C1P).

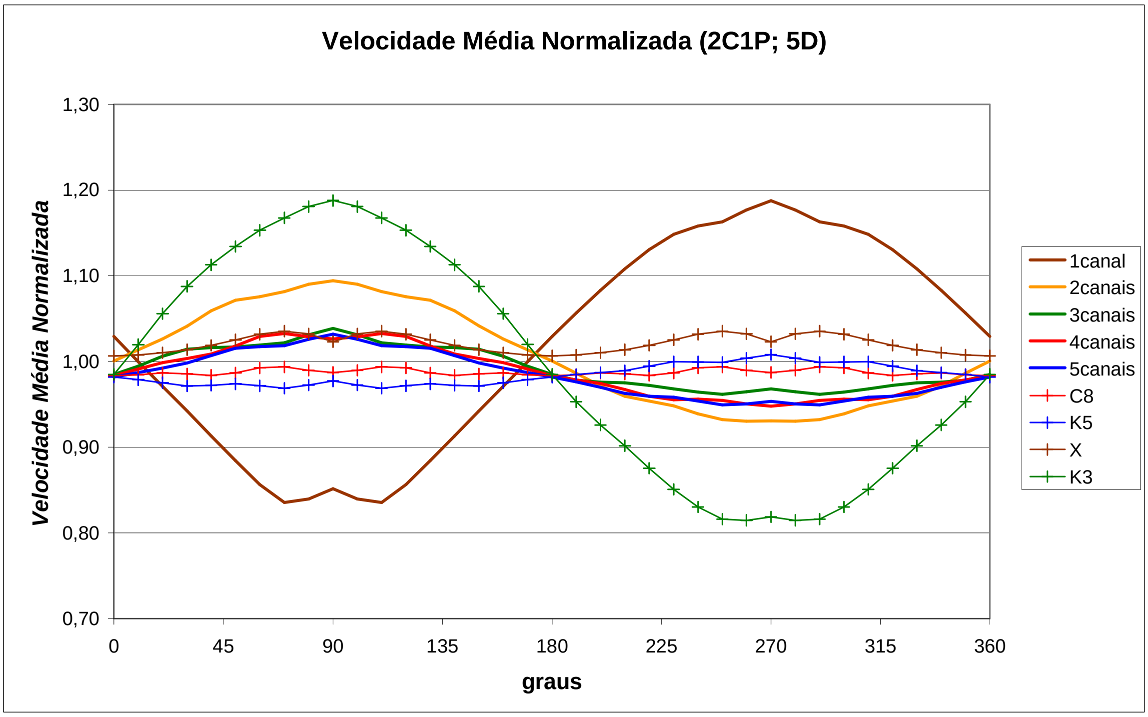

Figura C-6: Velocidade adimensional na seção transversal a 5D (2C1P).

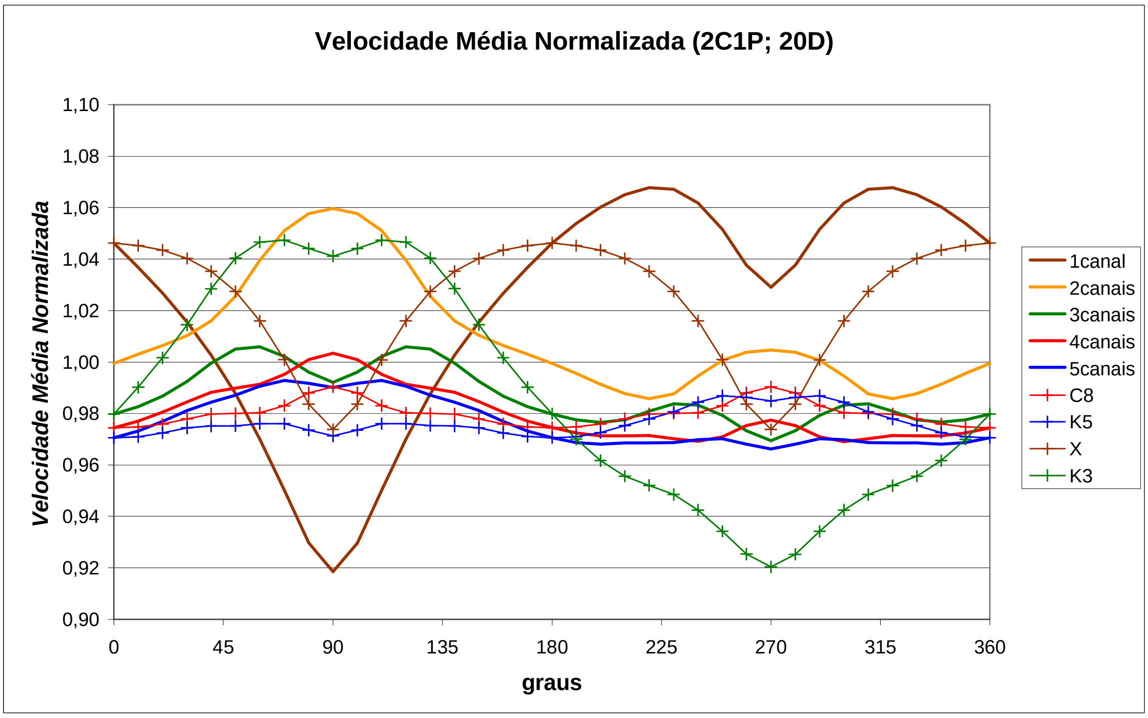

Figura C-7: Velocidade adimensional na seção transversal a 20D (2C1P).

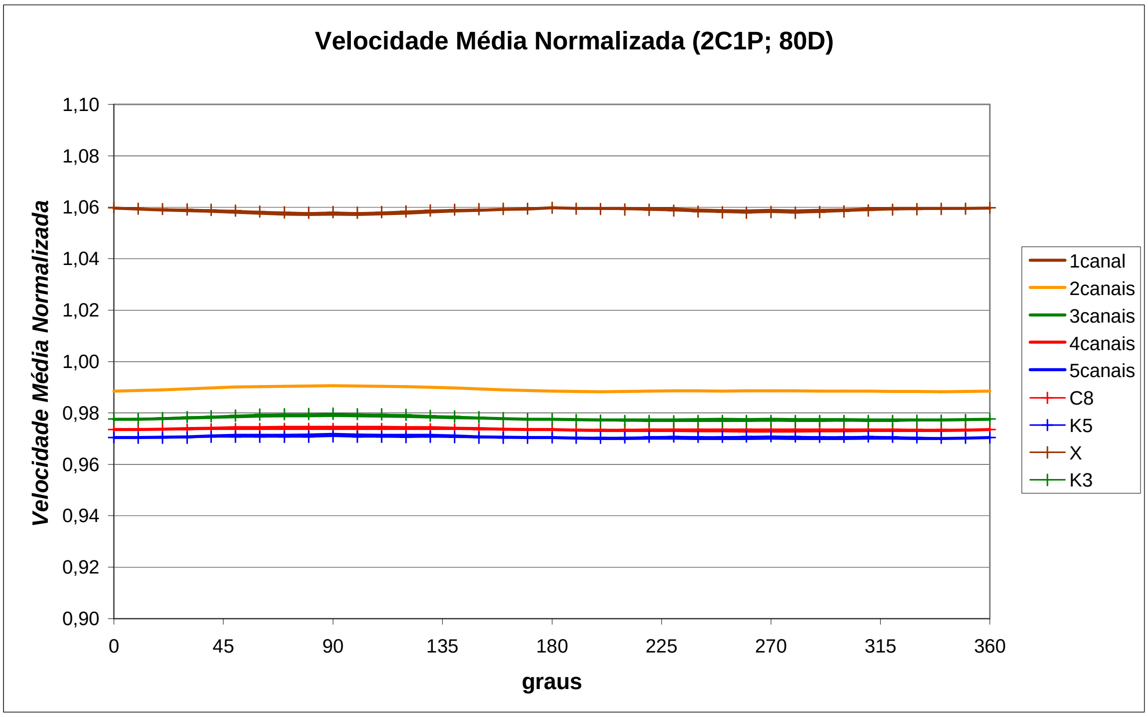

Figura C-8: Velocidade adimensional na seção transversal a 80D (2C1P).

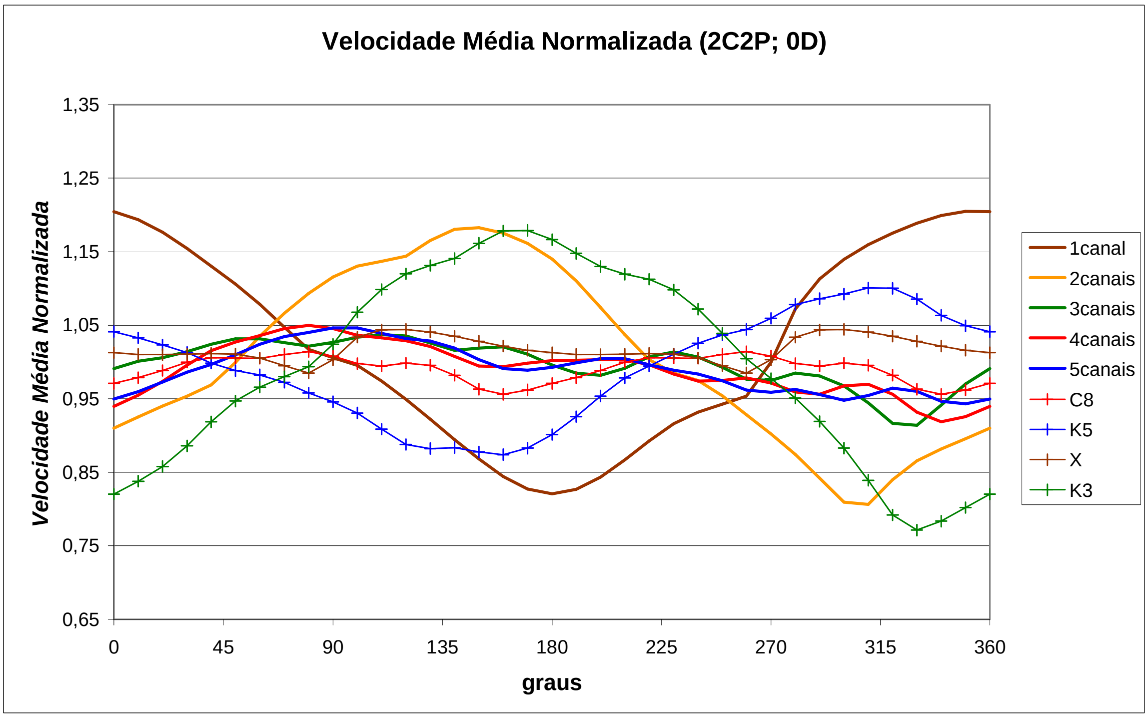

Figura C-9: Velocidade adimensional na seção transversal a 0D (2C2P).

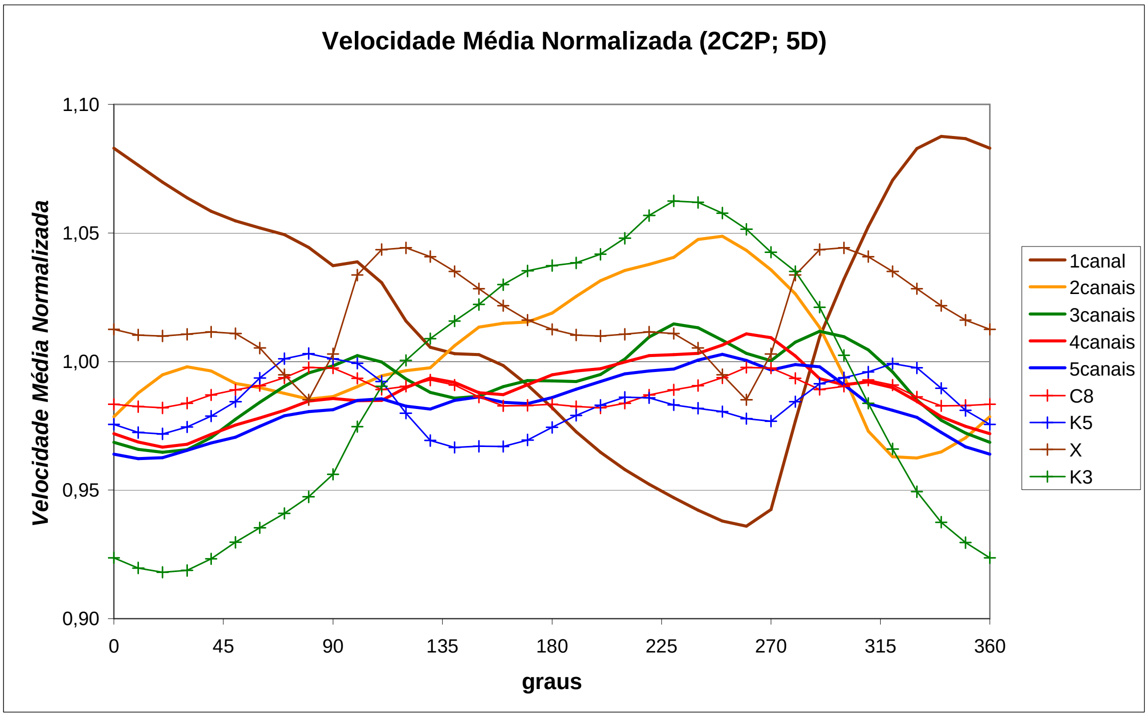

Figura C-10: Velocidade adimensional na seção transversal a 5D (2C2P).

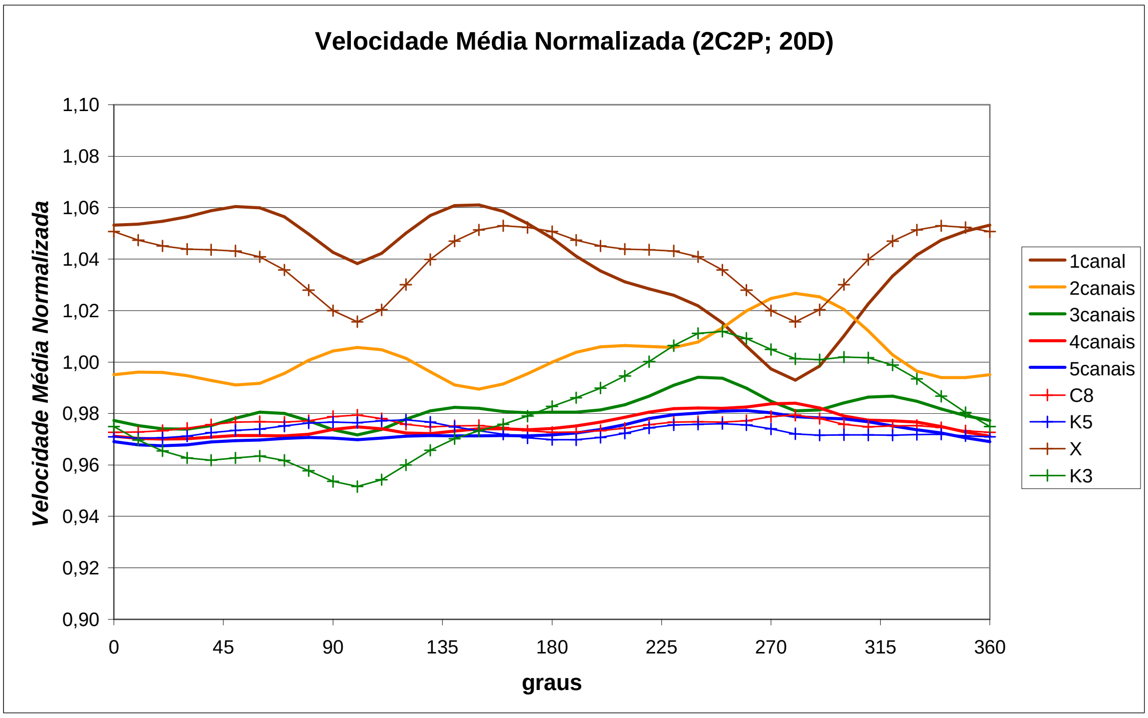

Figura C-11: Velocidade adimensional na seção transversal a 20D (2C2P).

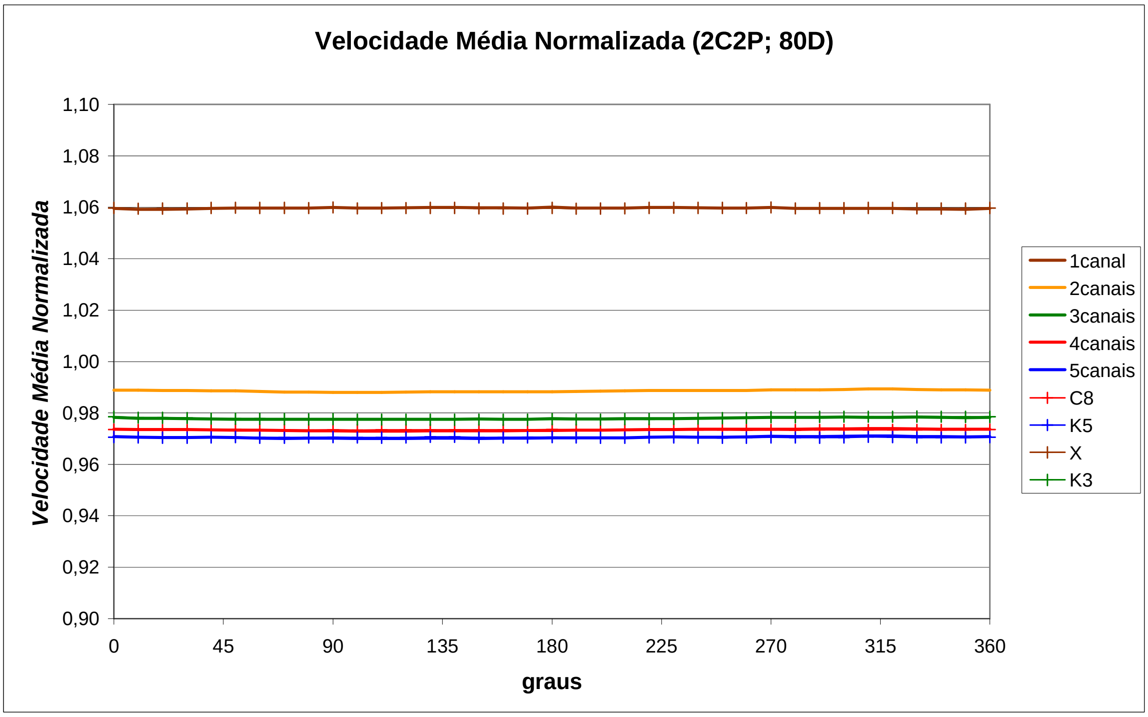

Figura C-12: Velocidade adimensional na seção transversal a 80D (2C2P).

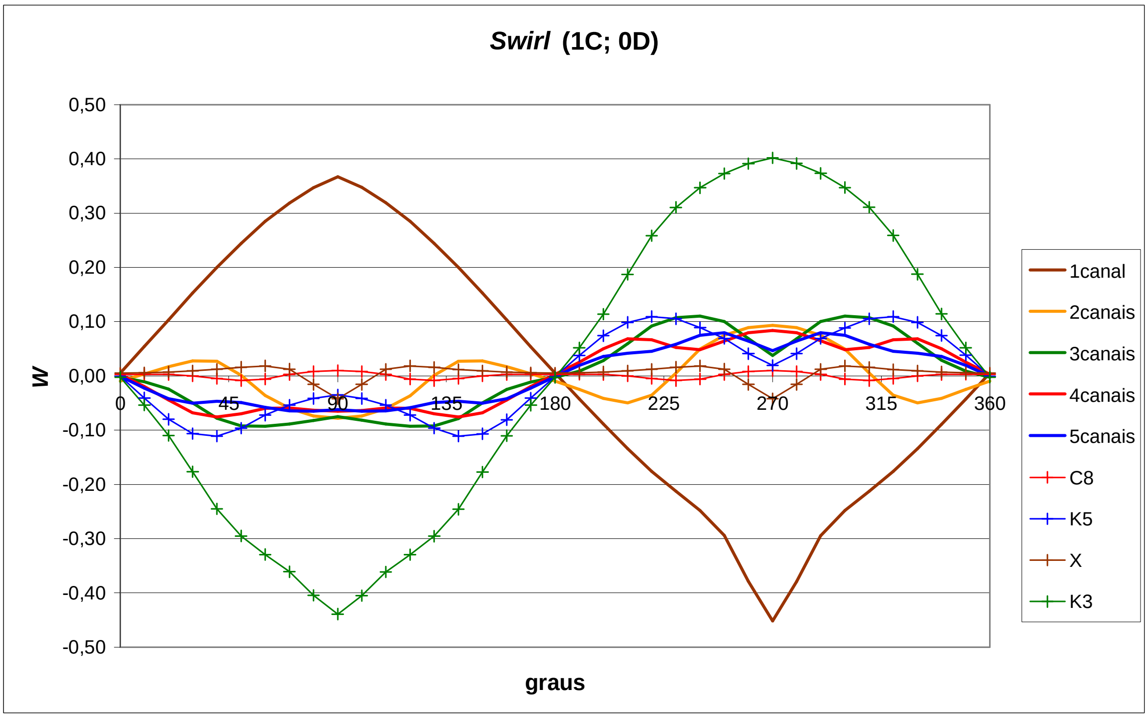

Figura C-13: *Swirl* na seção transversal a 0D (1C).

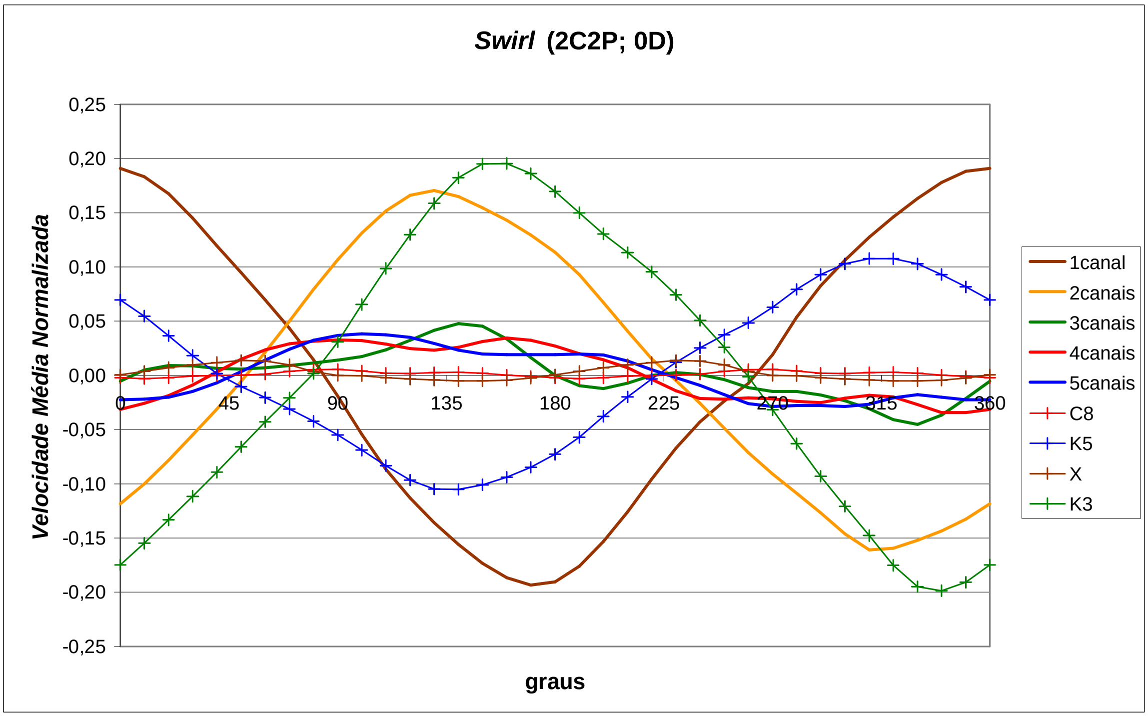

Figura C-14: *Swirl* na seção transversal a 0D (2C2P).

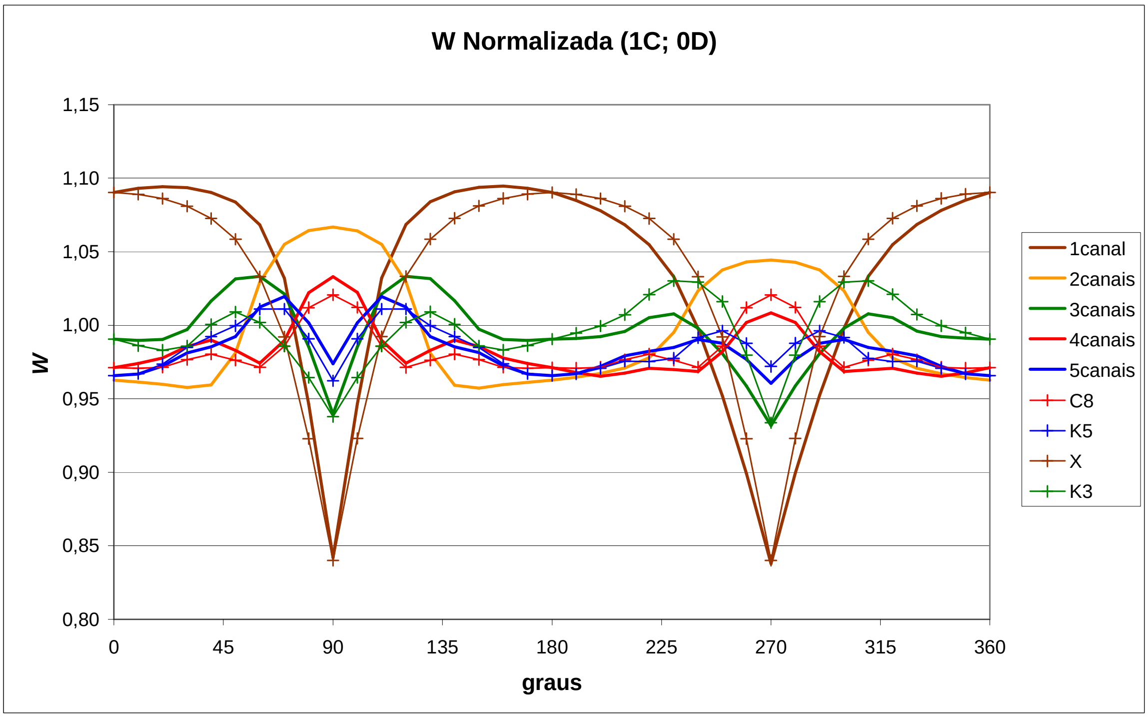

Figura C-15: Velocidade *w* na seção transversal a 0D (1C).

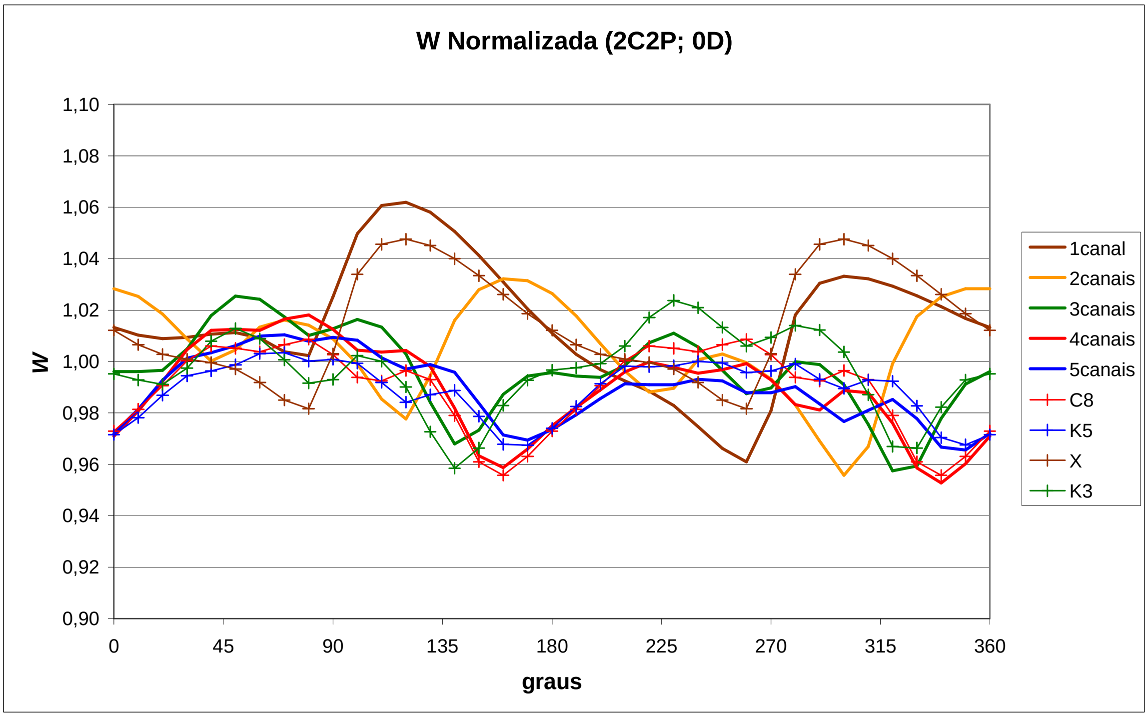

Figura C-16: Velocidade *w* na seção transversal a 0D (2C2P).

Apêndice D
Curvas: Fator na Seção Transversal.

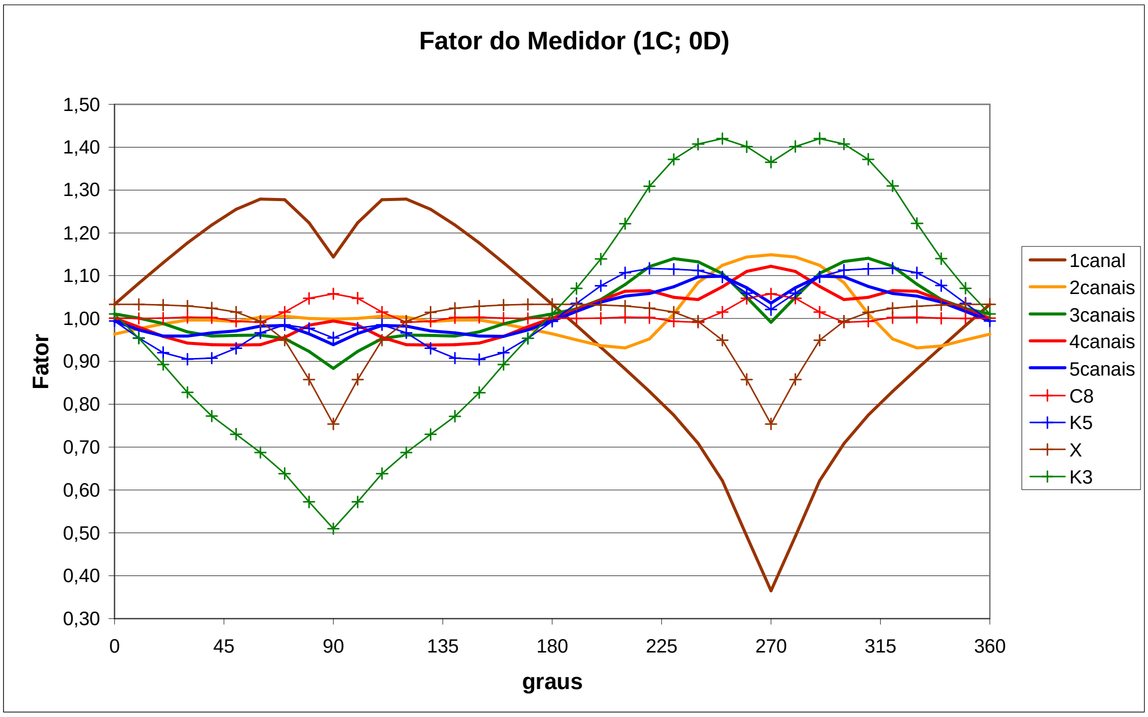

Figura D-1: Fator do medidor a 0D (1C).

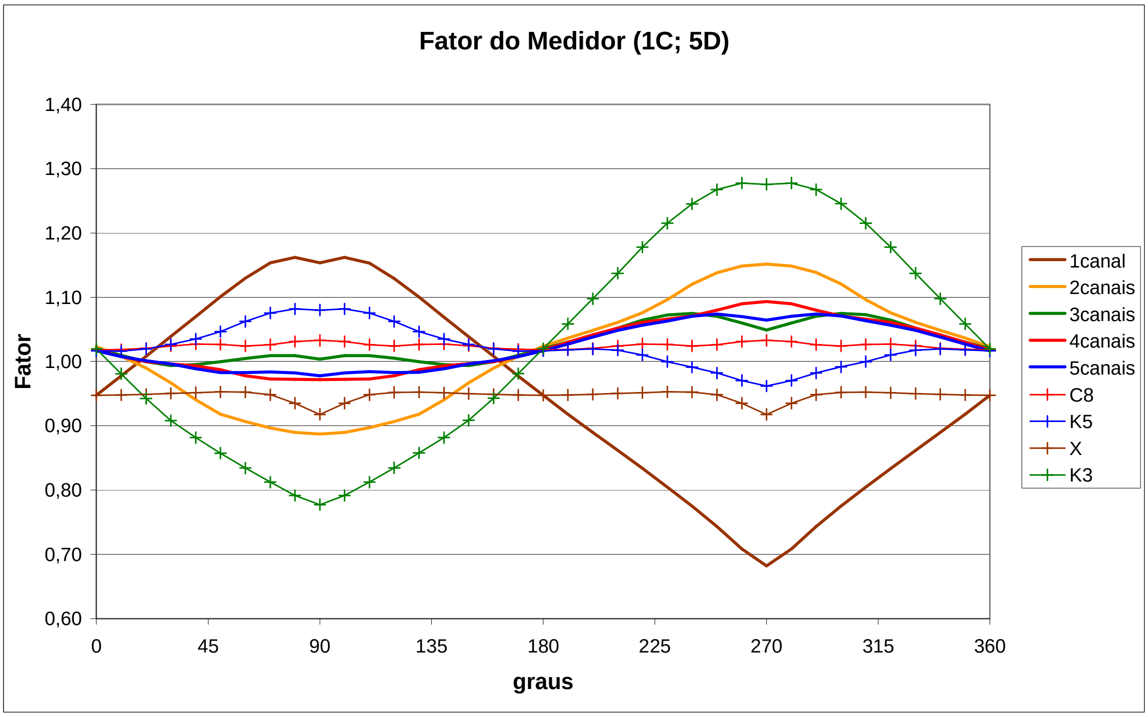

Figura D-2: Fator do medidor a 5D (1C).

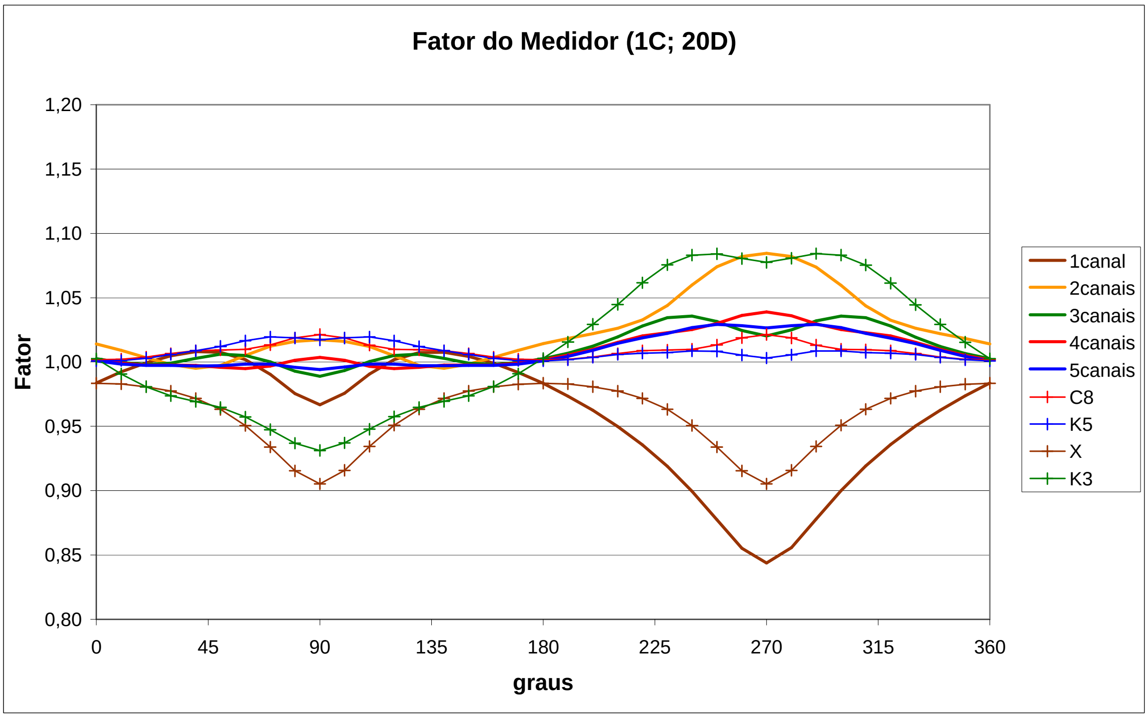

Figura D-3: Fator do medidor a 20D (1C).

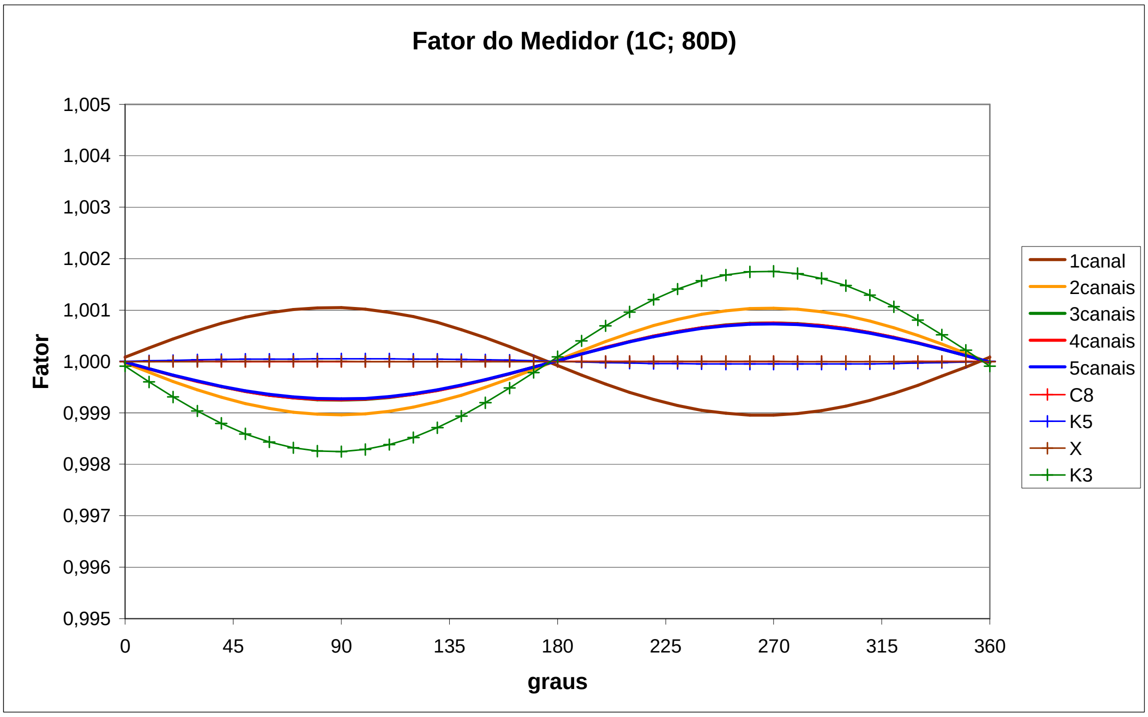

Figura D-4: Fator do medidor a 80D (1C).

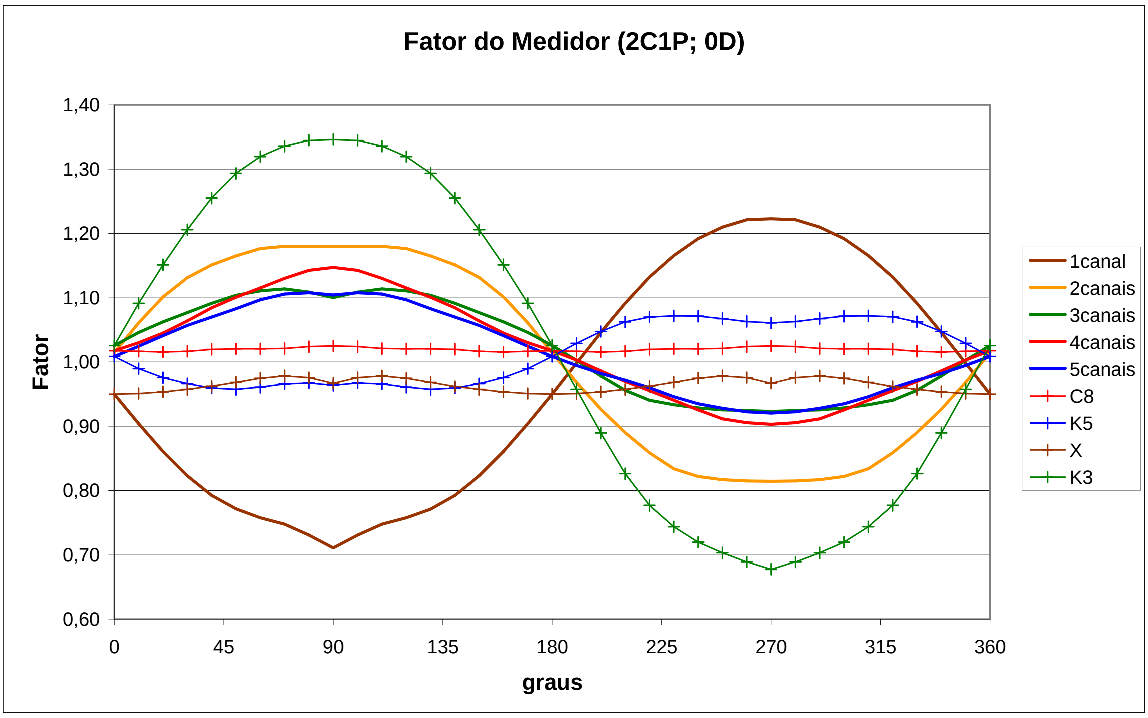

Figura D-5: Fator do medidor a 0D (2C1P).

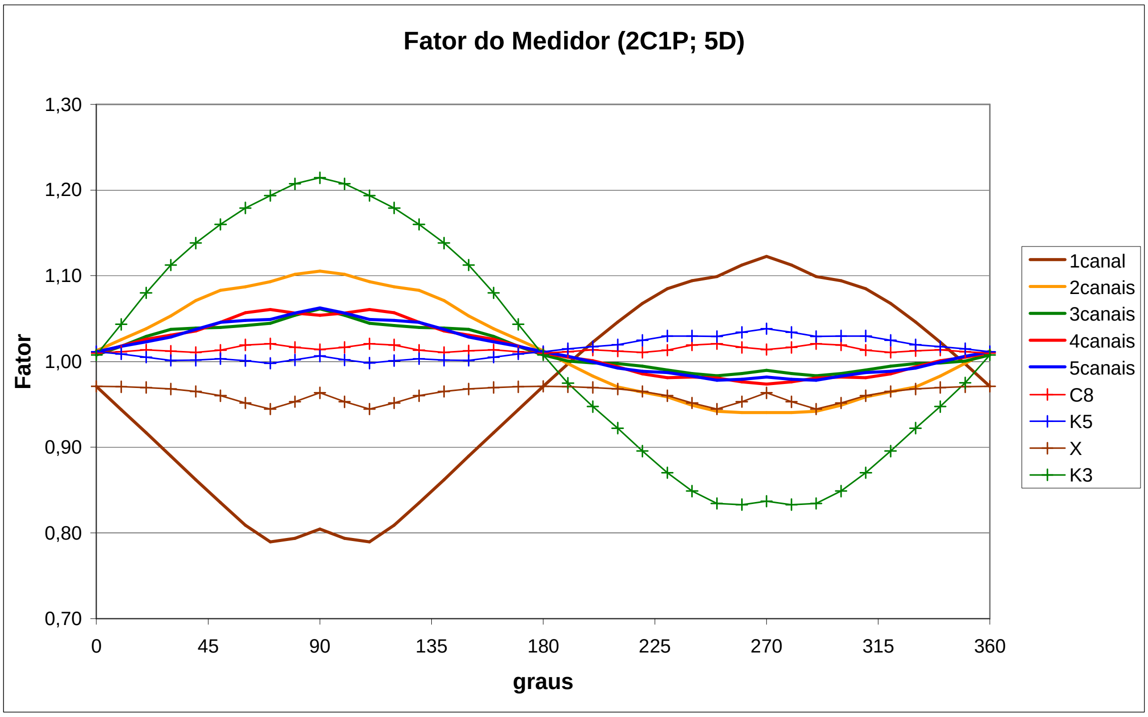

Figura D-6: Fator do medidor a 5D (2C1P).

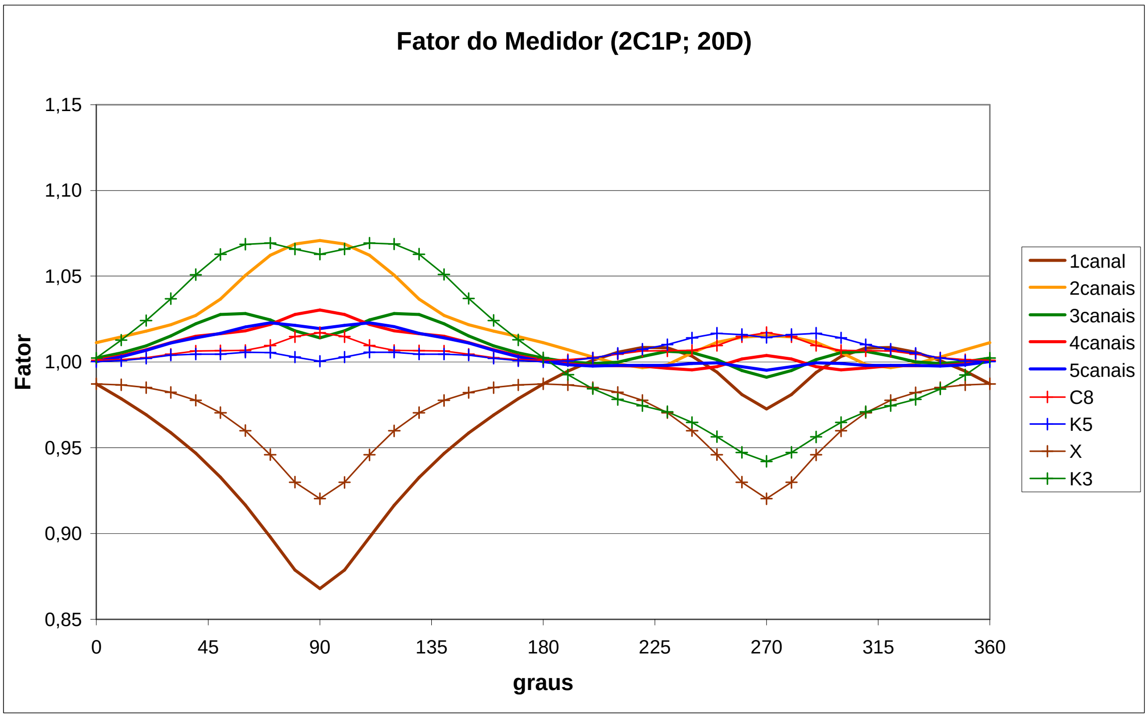

Figura D-7: Fator do medidor a 20D (2C1P).

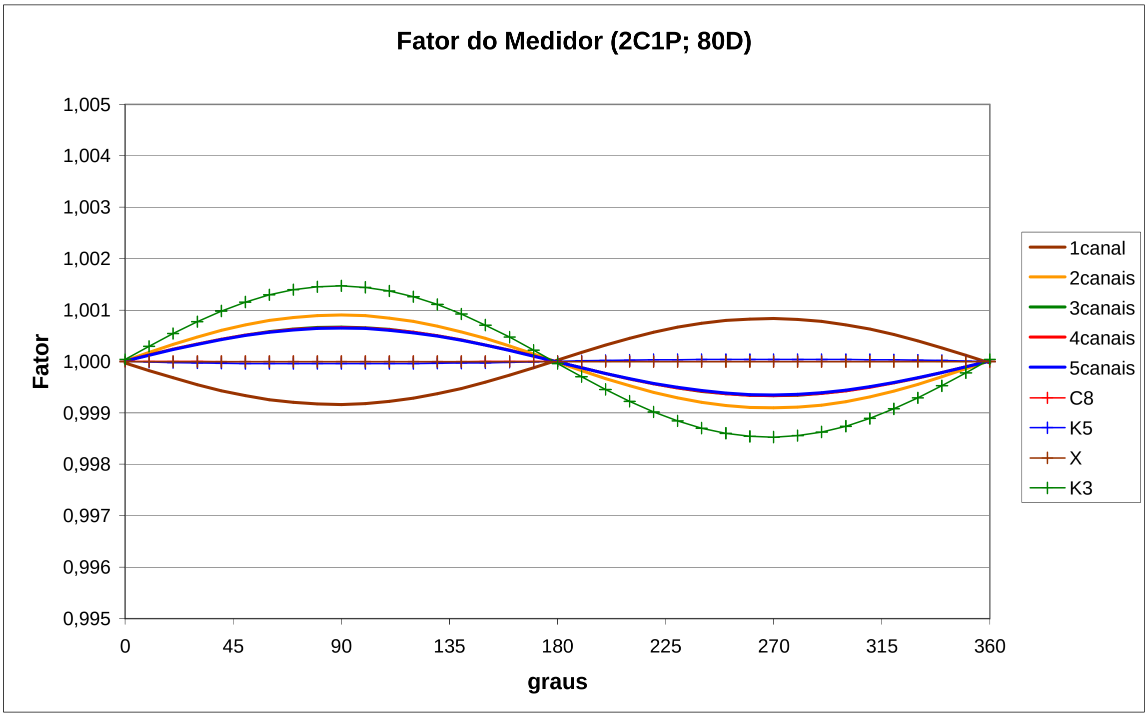

Figura D-8: Fator do medidor a 80D (2C1P).

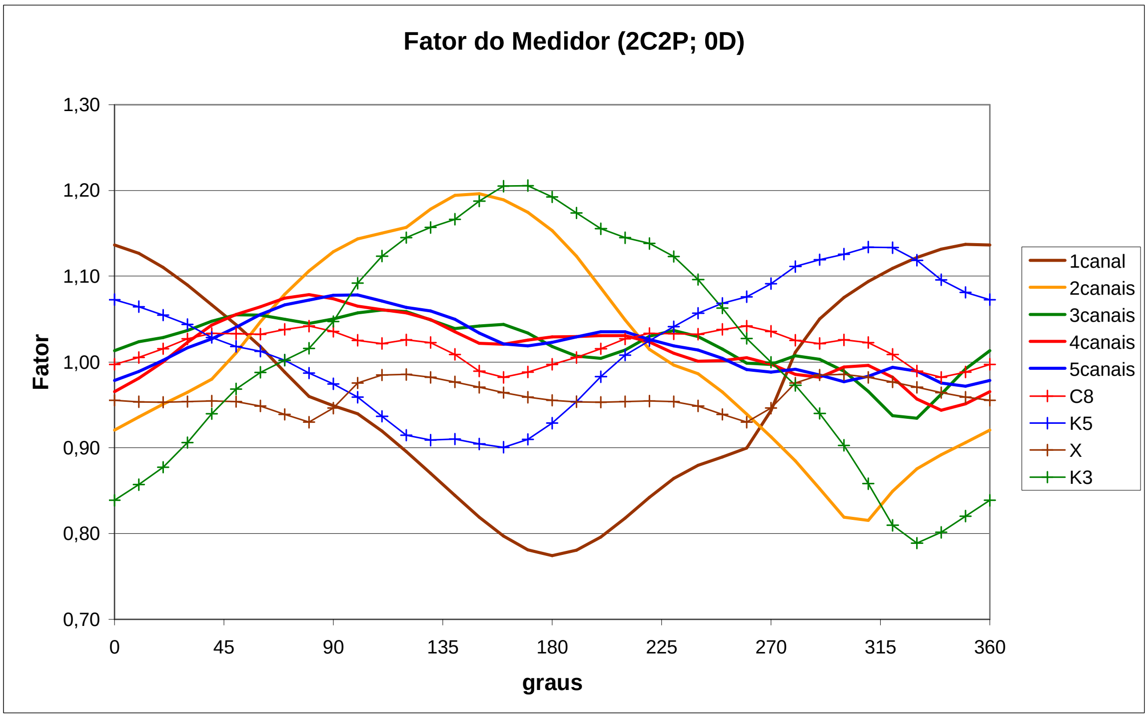

Figura D-9: Fator do medidor a 0D (2C2P).

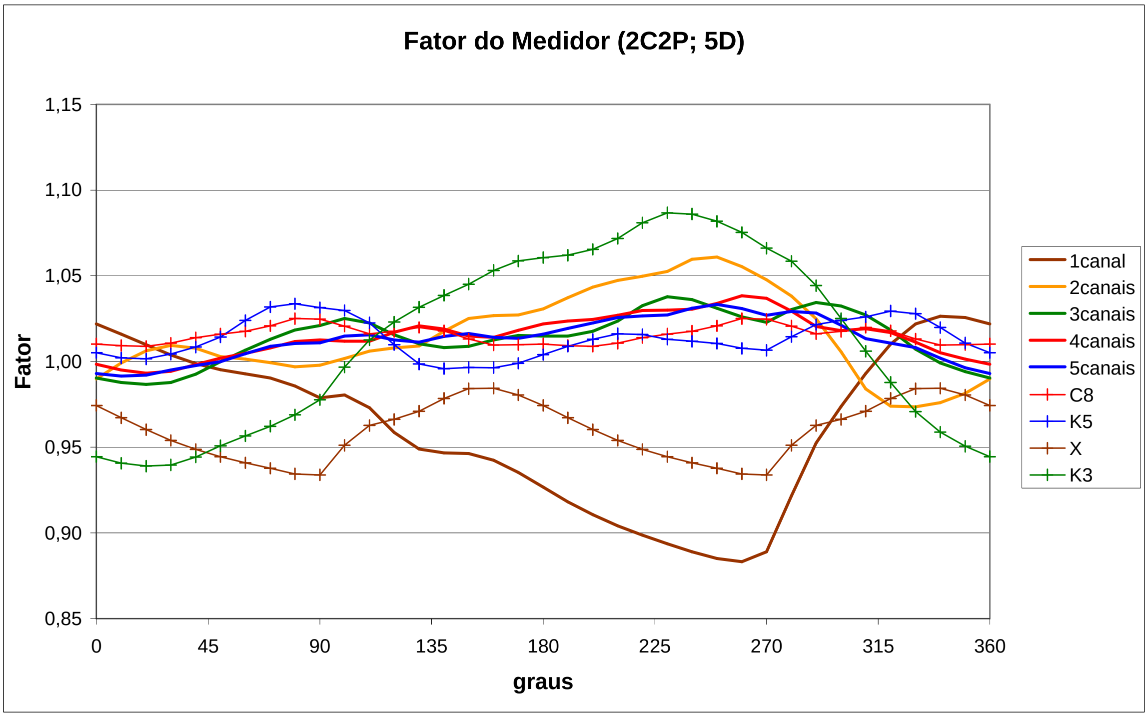

Figura D-10: Fator do medidor a 5D (2C2P).

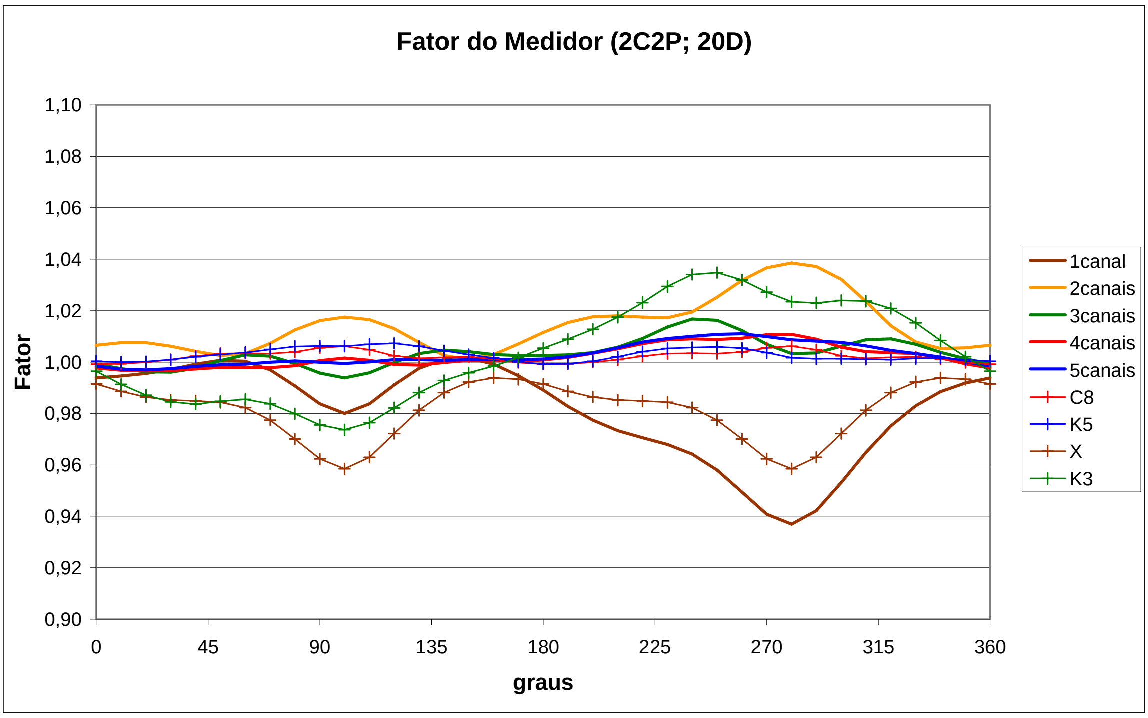

Figura D-11: Fator do medidor a 20D (2C2P).

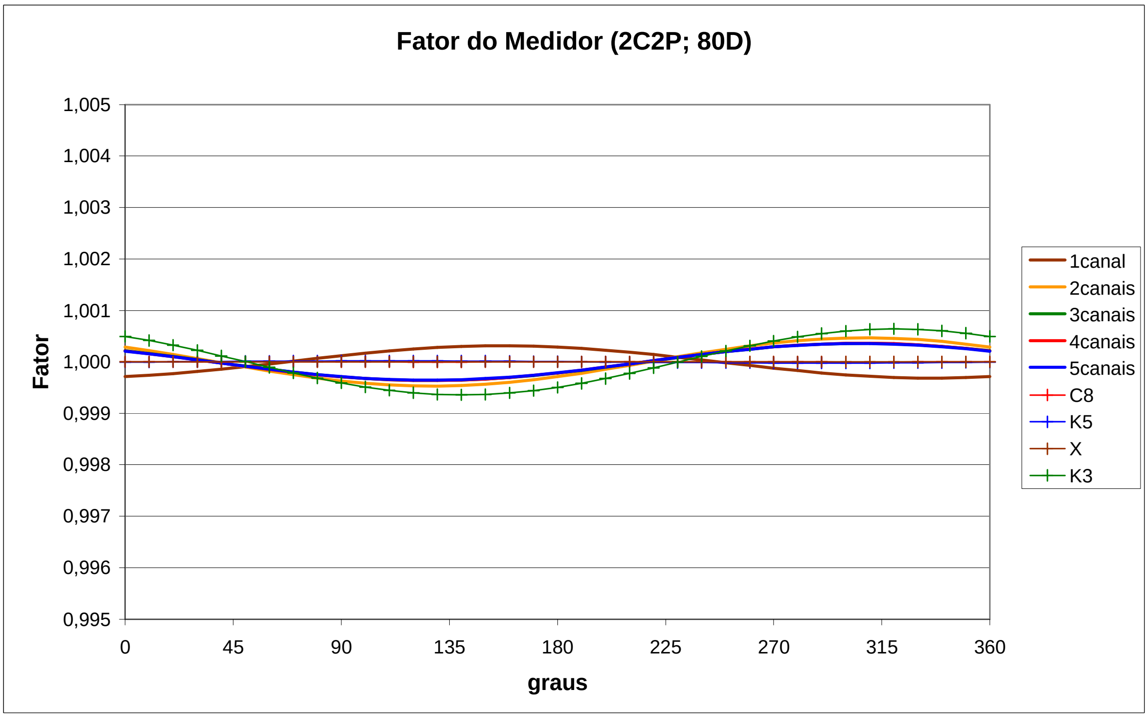

Figura D-12: Fator do medidor a 80D (2C2P).

Apêndice E
Curvas: Parâmetros de Diagnóstico

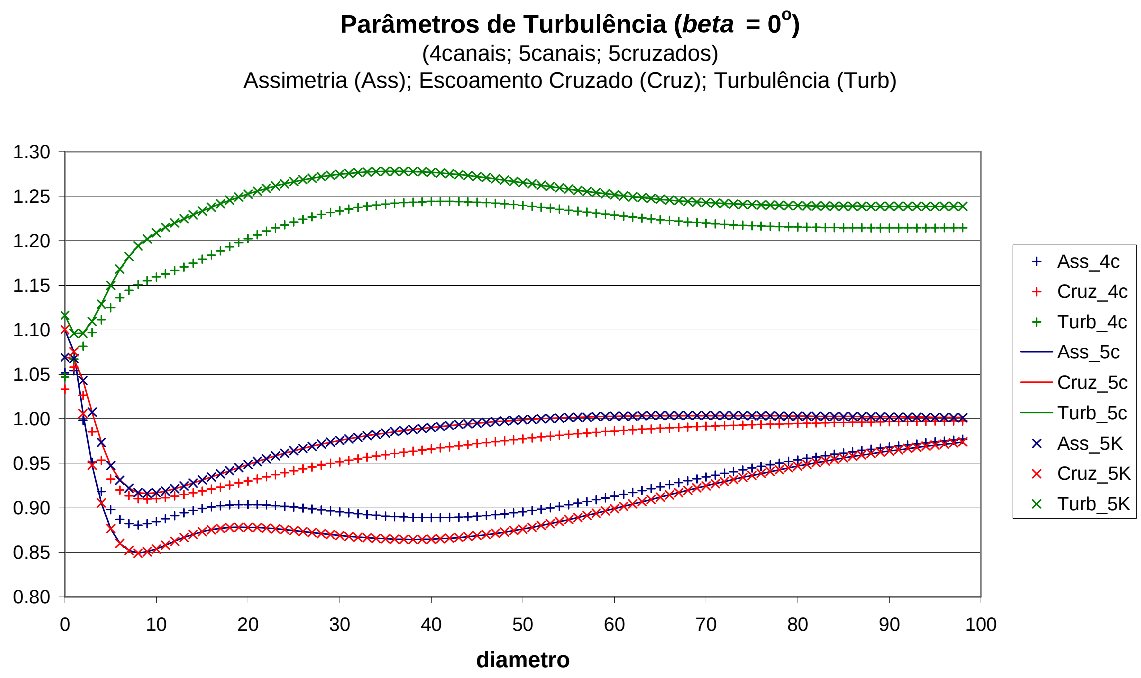

Figura E-1: Parâmetros de diagnóstico para $\beta = 0º$ (1C).

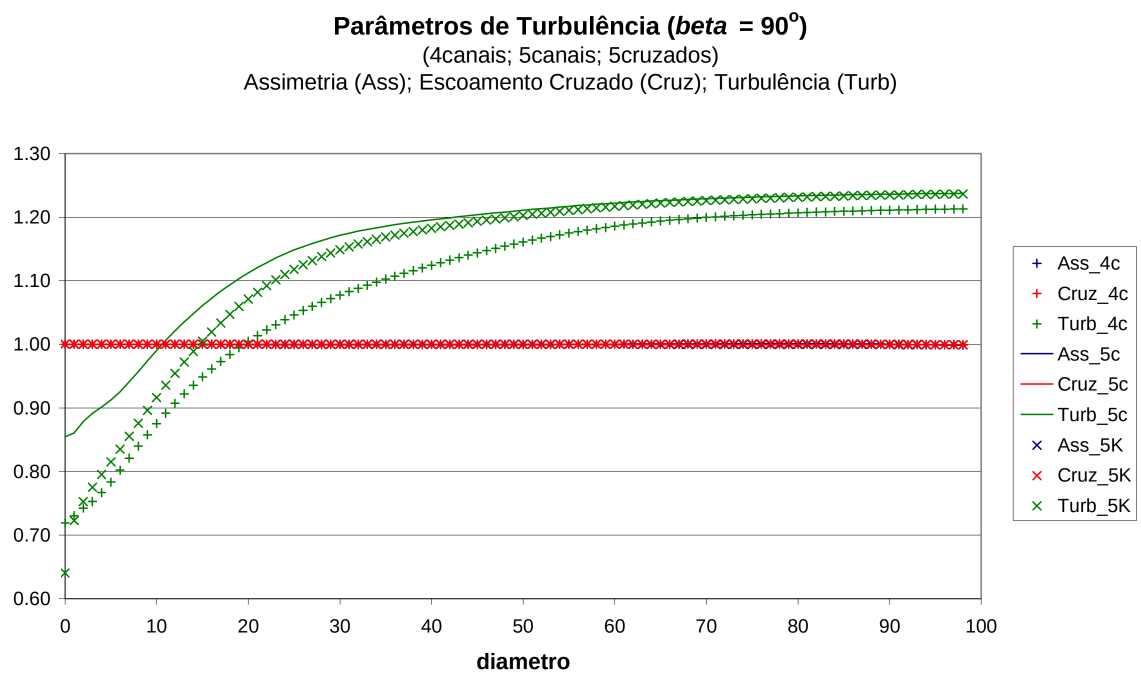

Figura E-2: Parâmetros de diagnóstico para $\beta = 90º$ (1C).

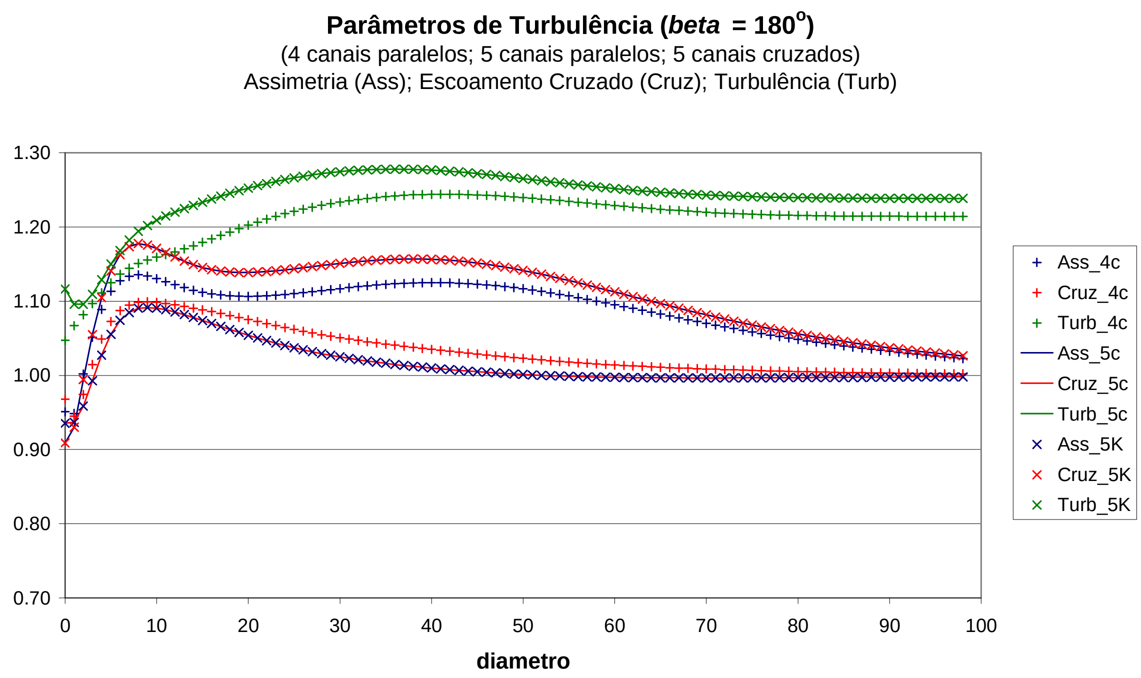

Figura E-3: Parâmetros de diagnóstico para β = 180º (1C).

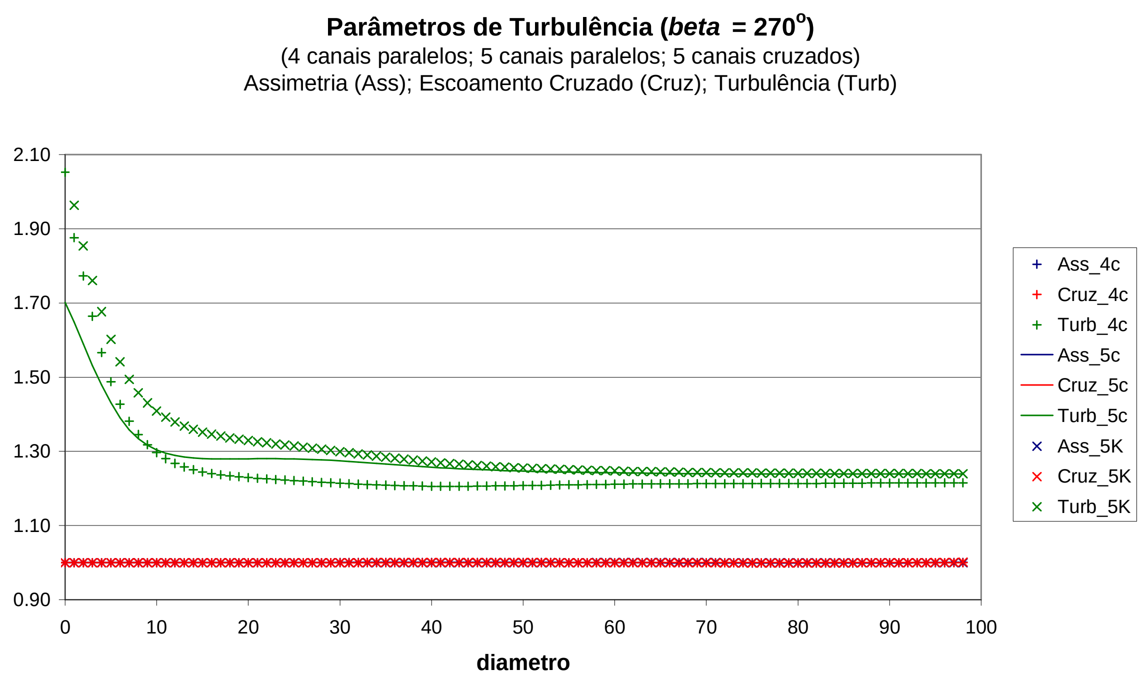

Figura E-4: Parâmetros de diagnóstico para β = 270º (1C).

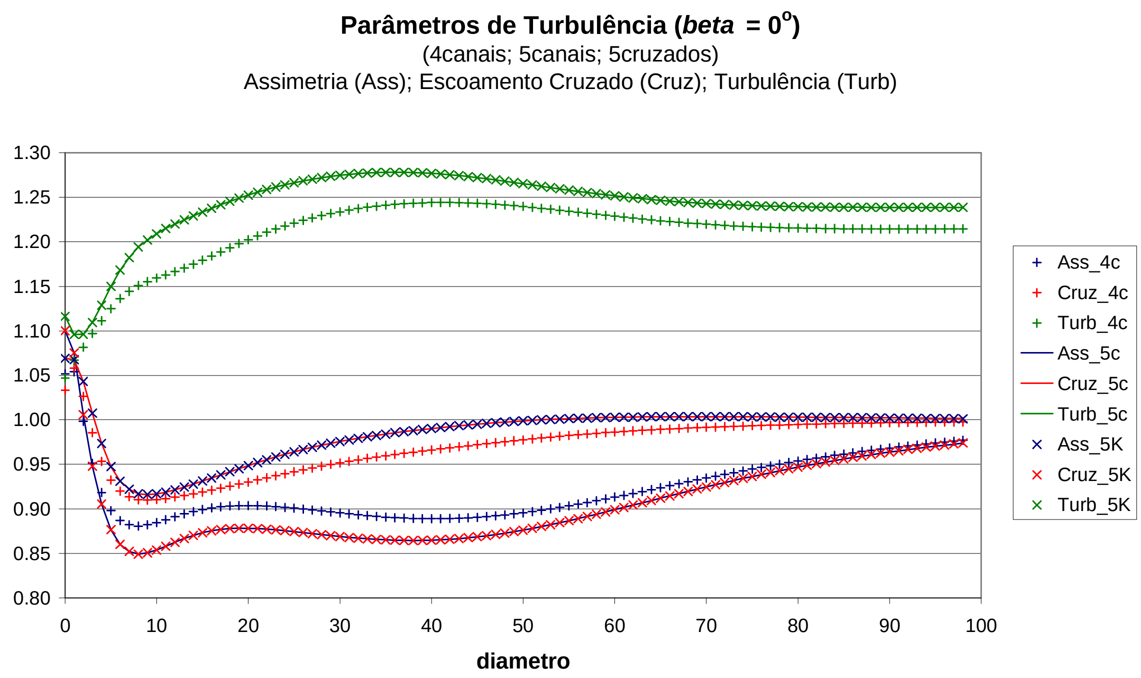

Figura E-5: Parâmetros de diagnóstico para β = 0º (2C1P).

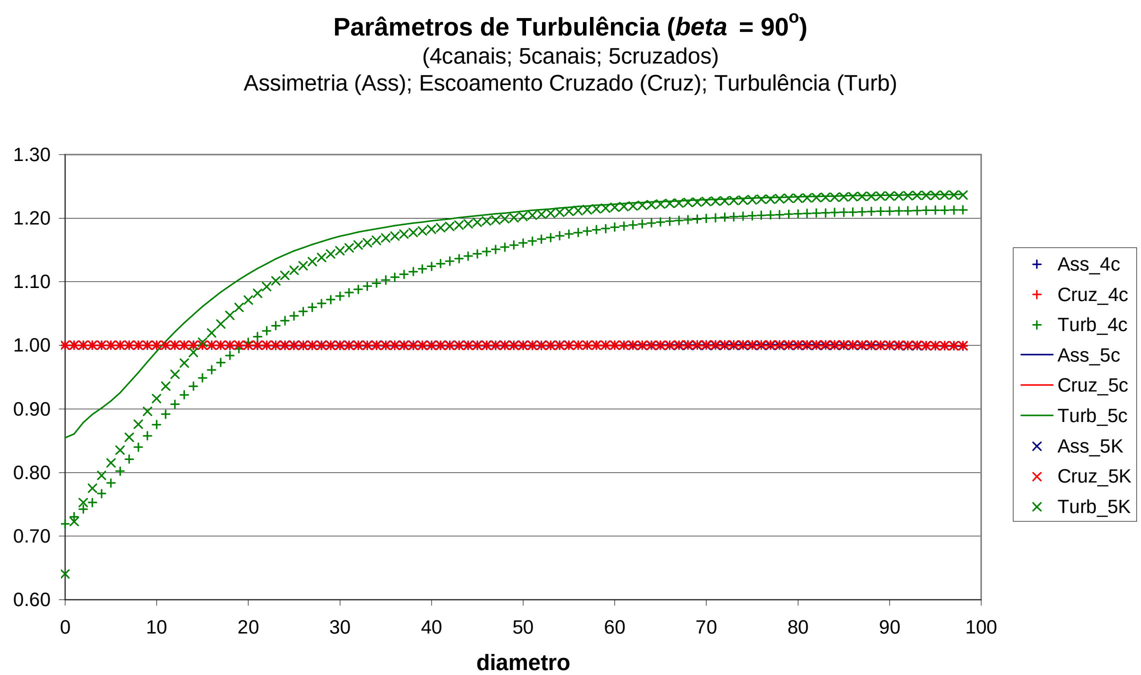

Figura E-6: Parâmetros de diagnóstico para β = 90º (2C1P).

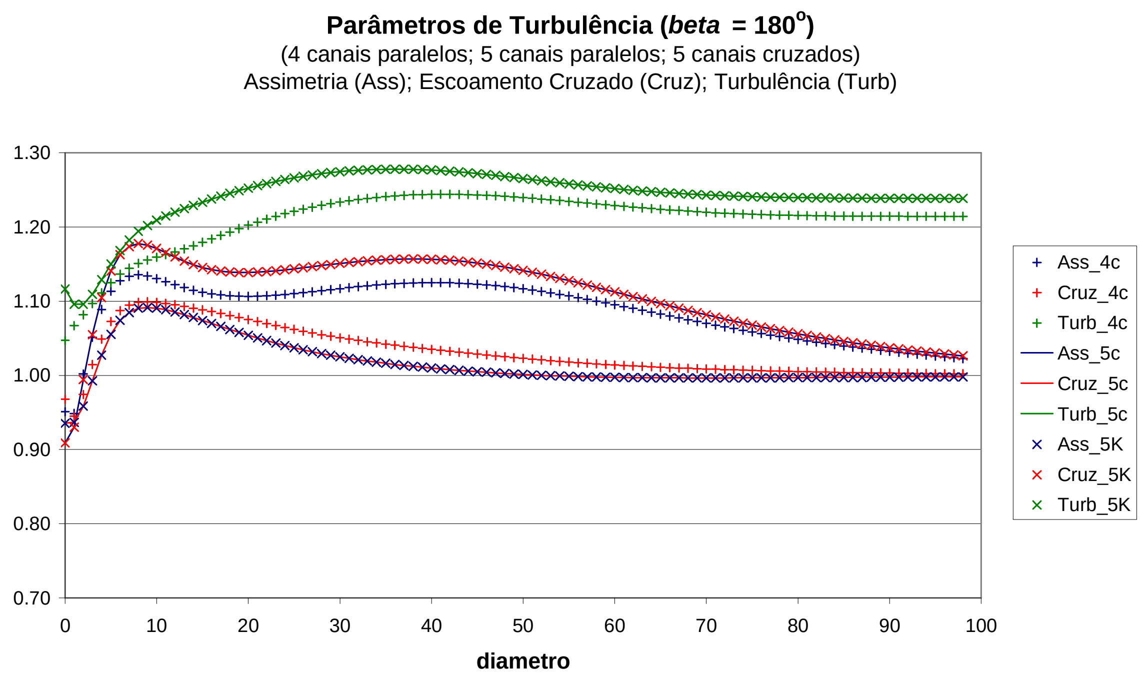

Figura E-7: Parâmetros de diagnóstico para β = 180º (2C1P).

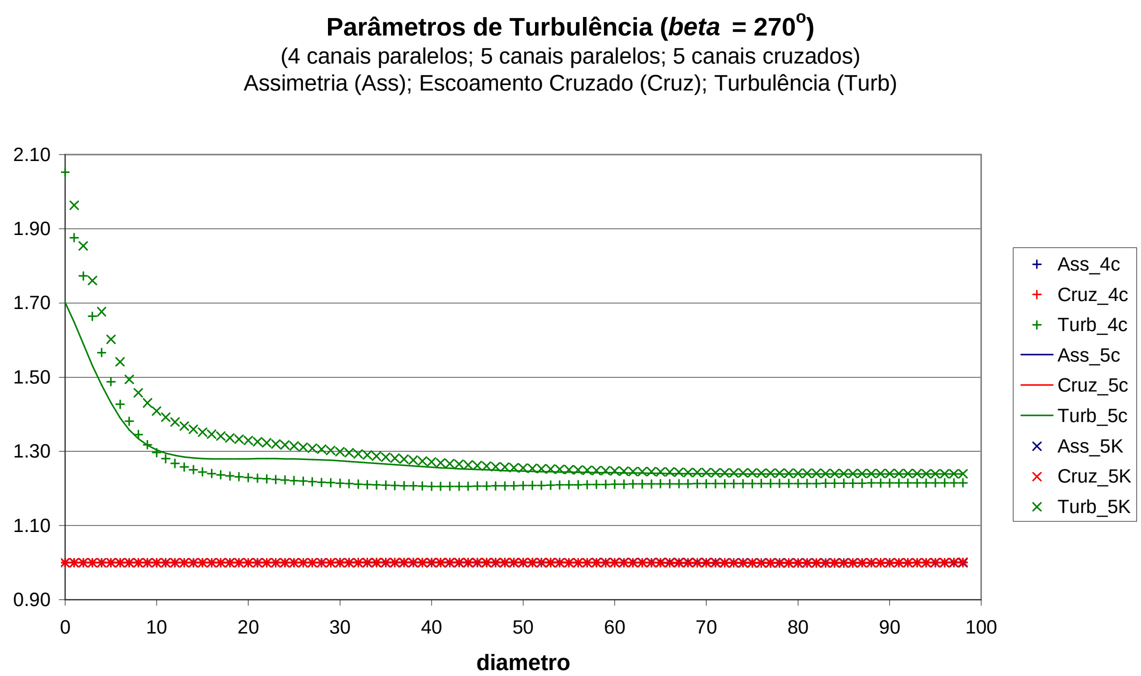

Figura E-8: Parâmetros de diagnóstico para β = 270º (2C1P).

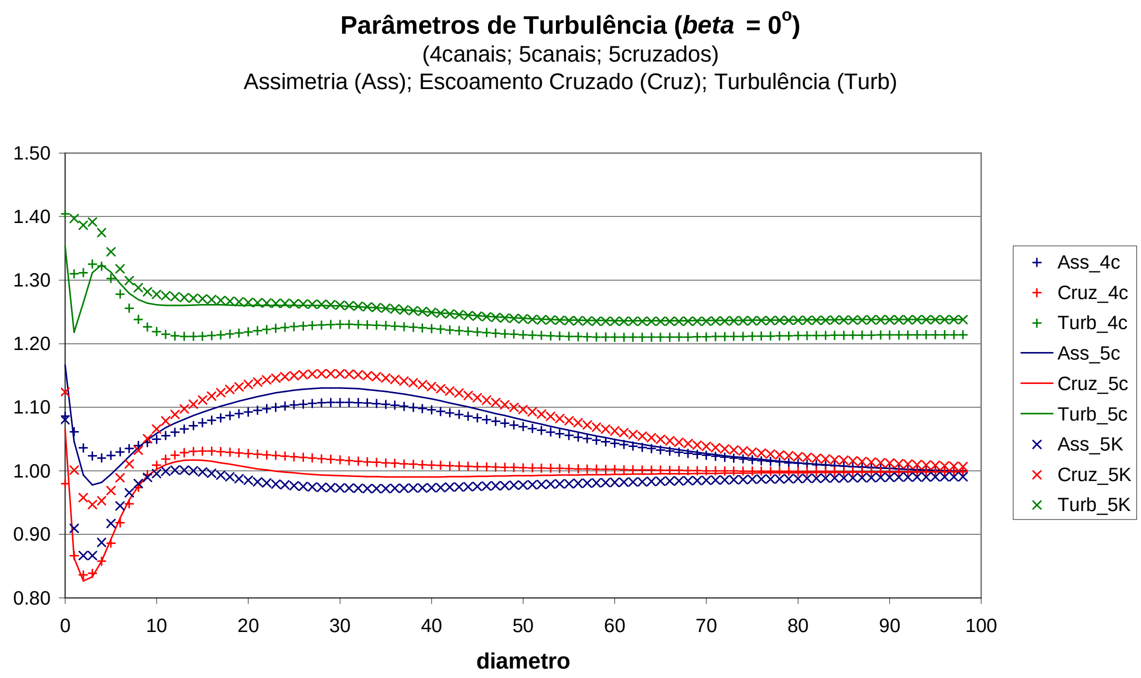

Figura E-9: Parâmetros de diagnóstico para β = 0º (2C2P).

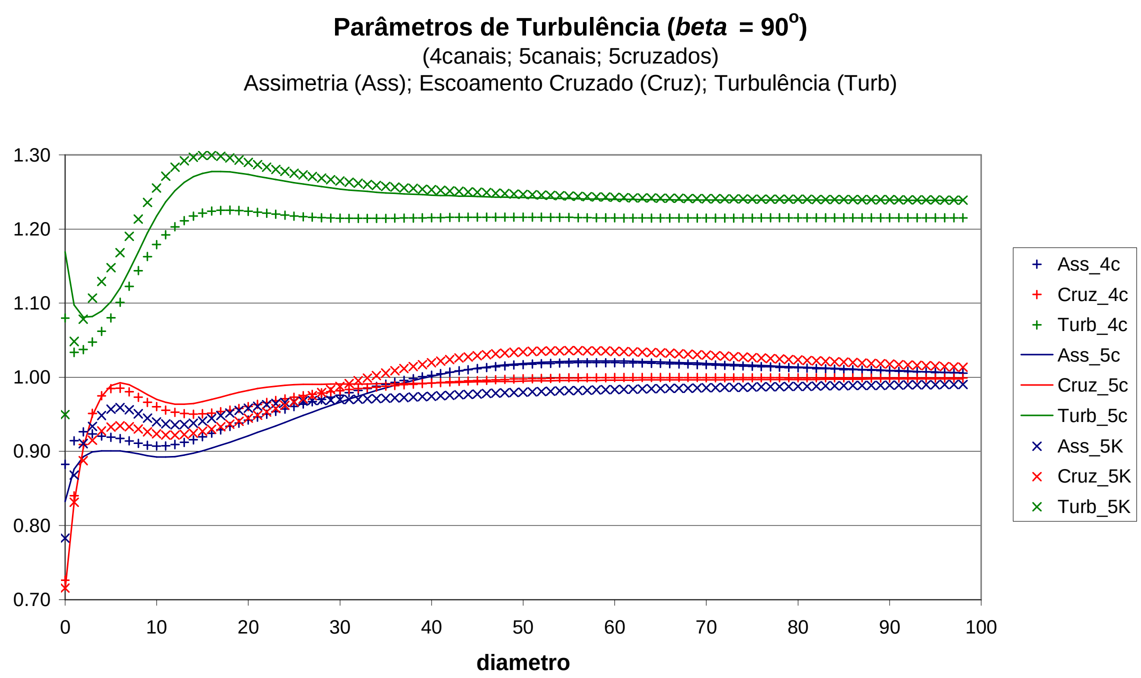

Figura E-10: Parâmetros de diagnóstico para β = 90º (2C2P).

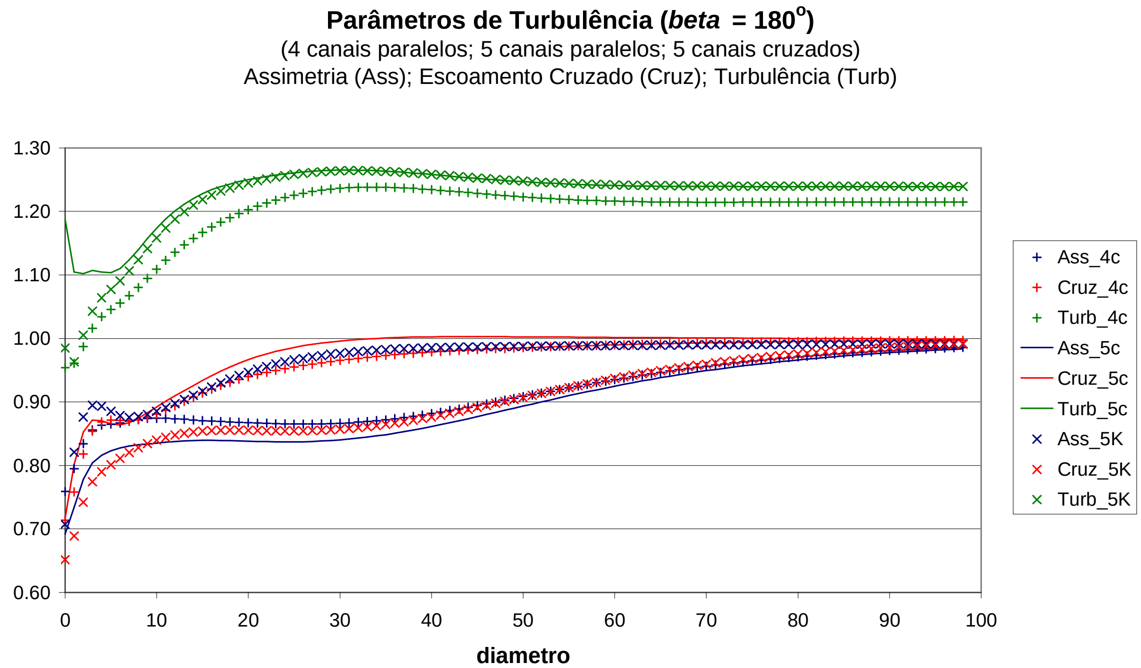

Figura E-11: Parâmetros de diagnóstico para β = 180º (2C2P).

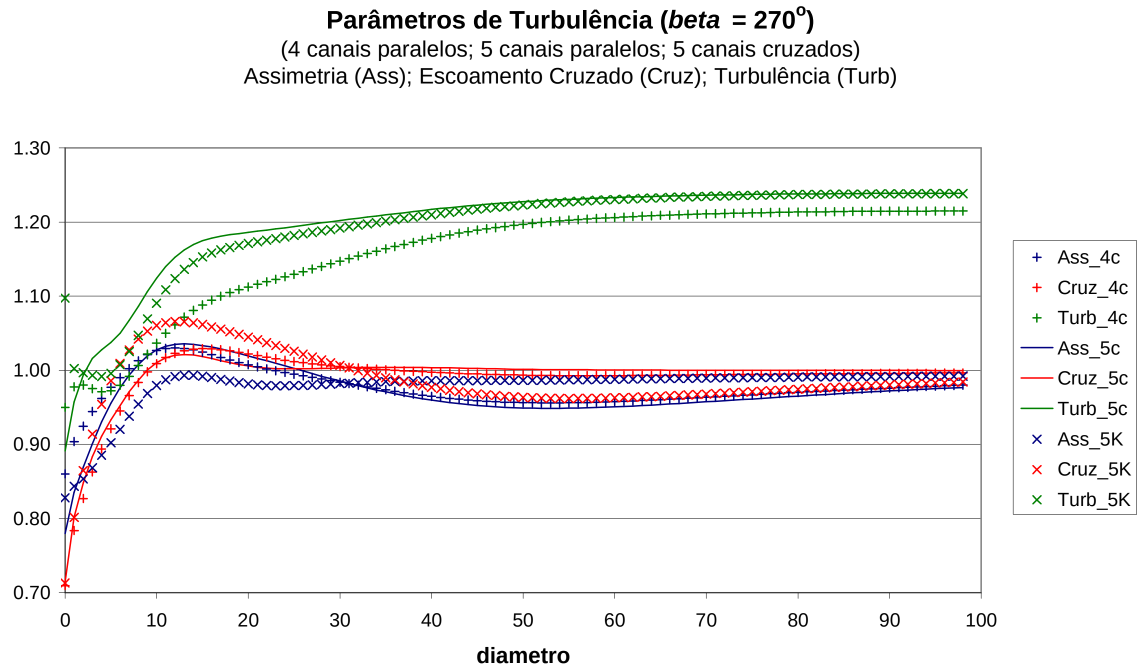

Figura E-12: Parâmetros de diagnóstico para β = 270º (2C2P).

Apêndice F
Degrau-Duplo: Velocidade e Fator

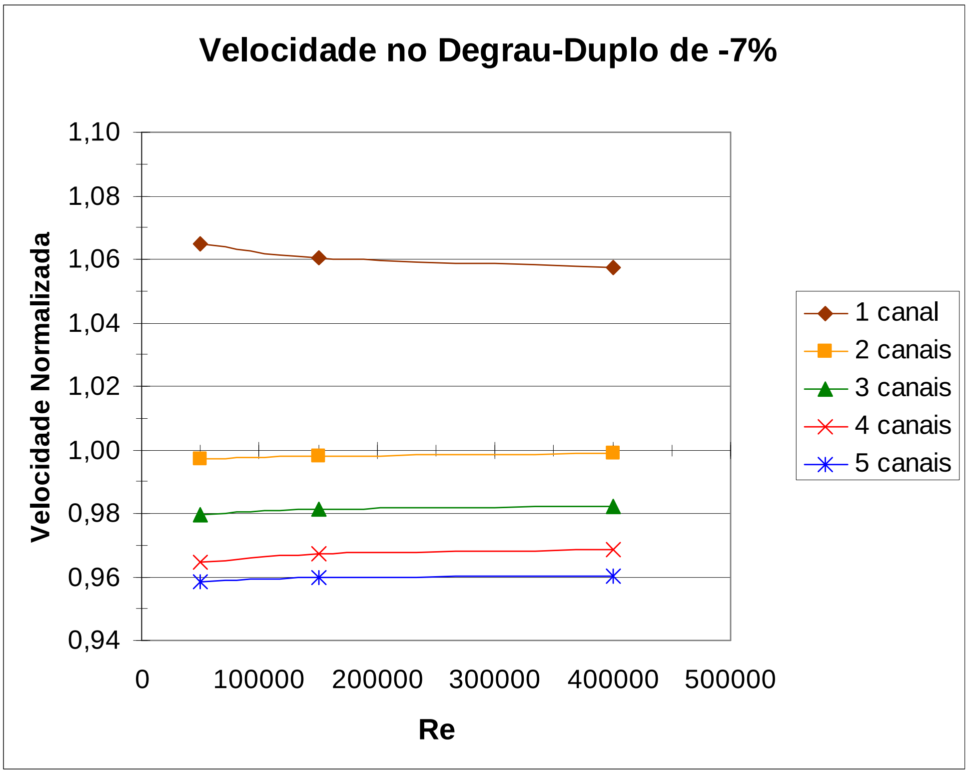

Figura F-1: Velocidade para o degrau-duplo convergente de –7%.

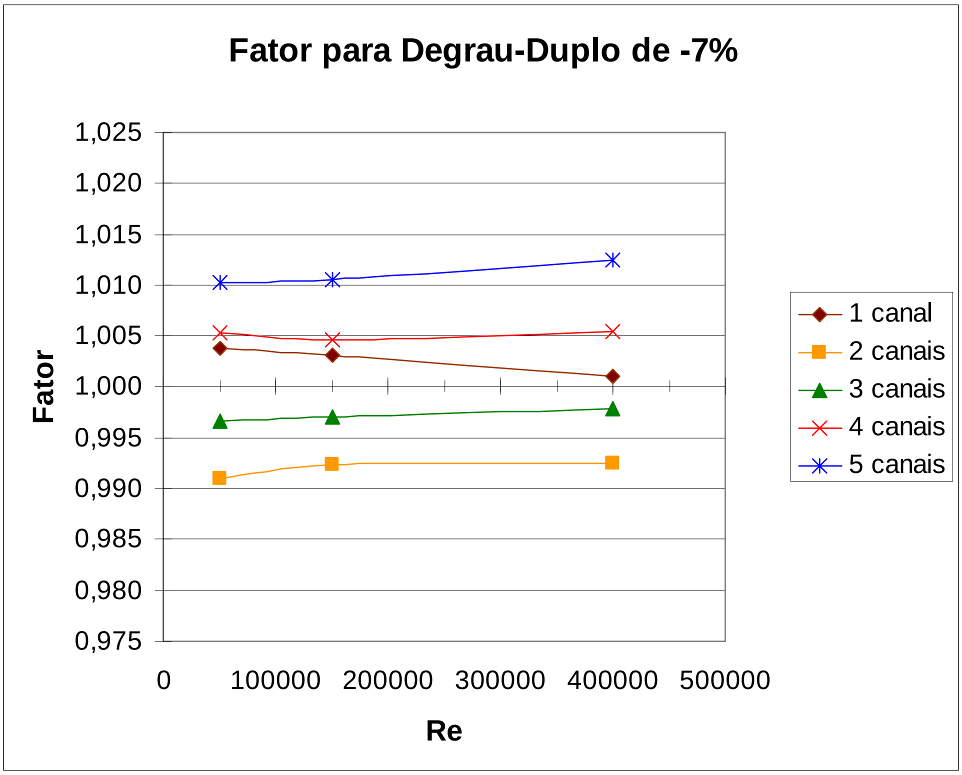

Figura F-2: Fator para degrau-duplo convergente de –7%.

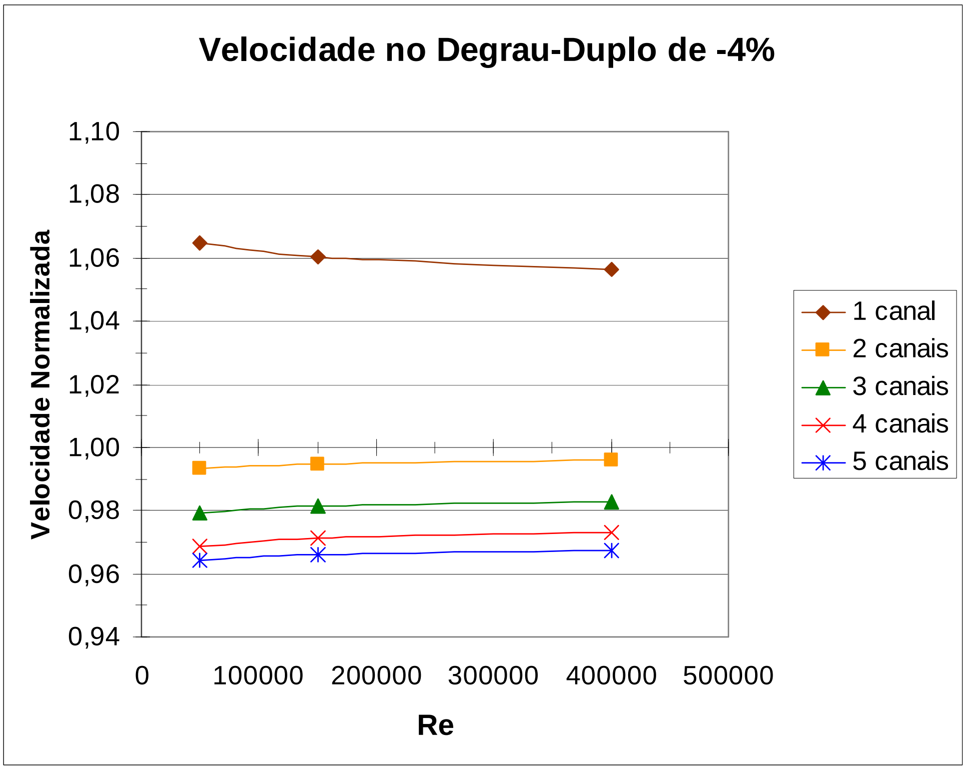

Figura F-3: Velocidade para o degrau-duplo convergente de –4%.

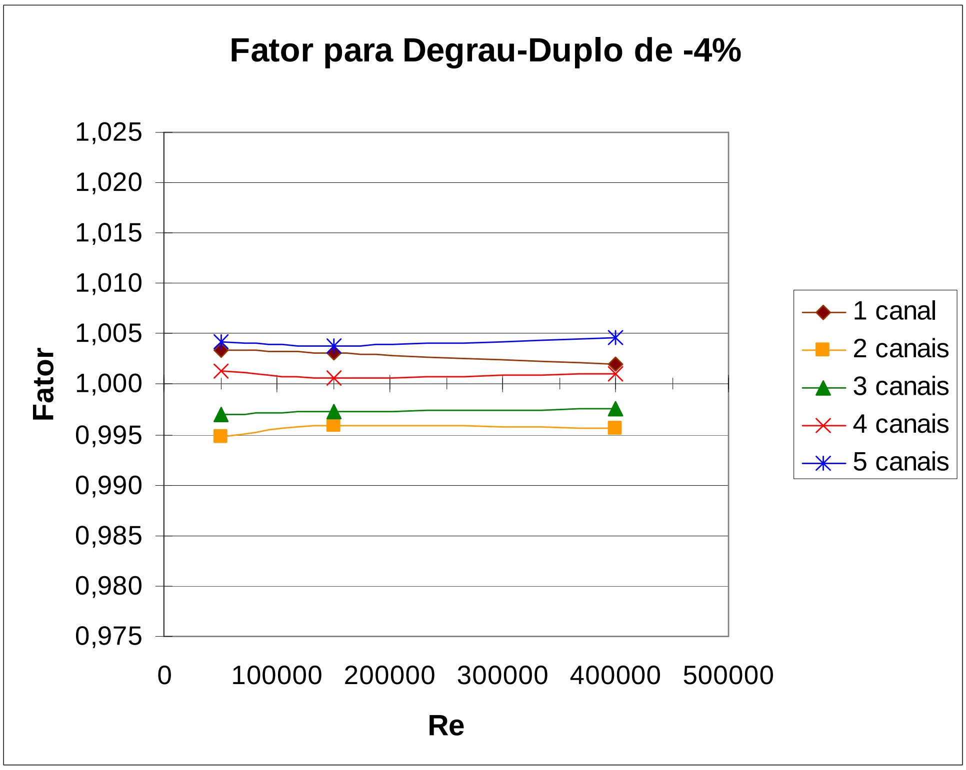

Figura F-4: Fator para o degrau-duplo convergente de –4%.

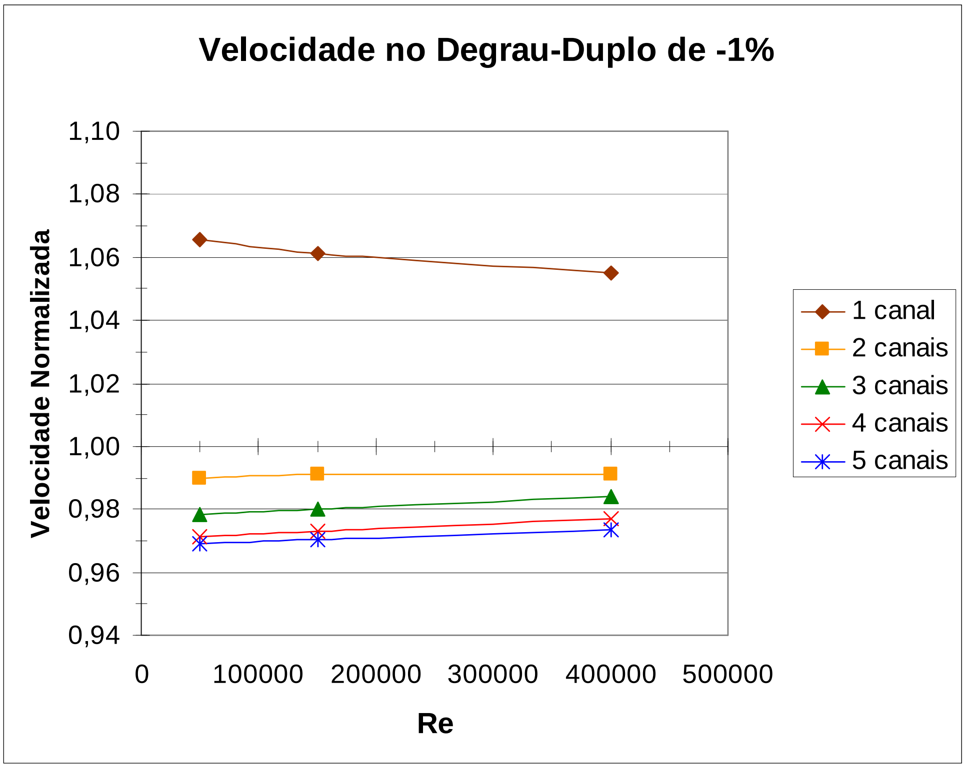

Figura F-5: Velocidade para o degrau-duplo convergente de –1%.

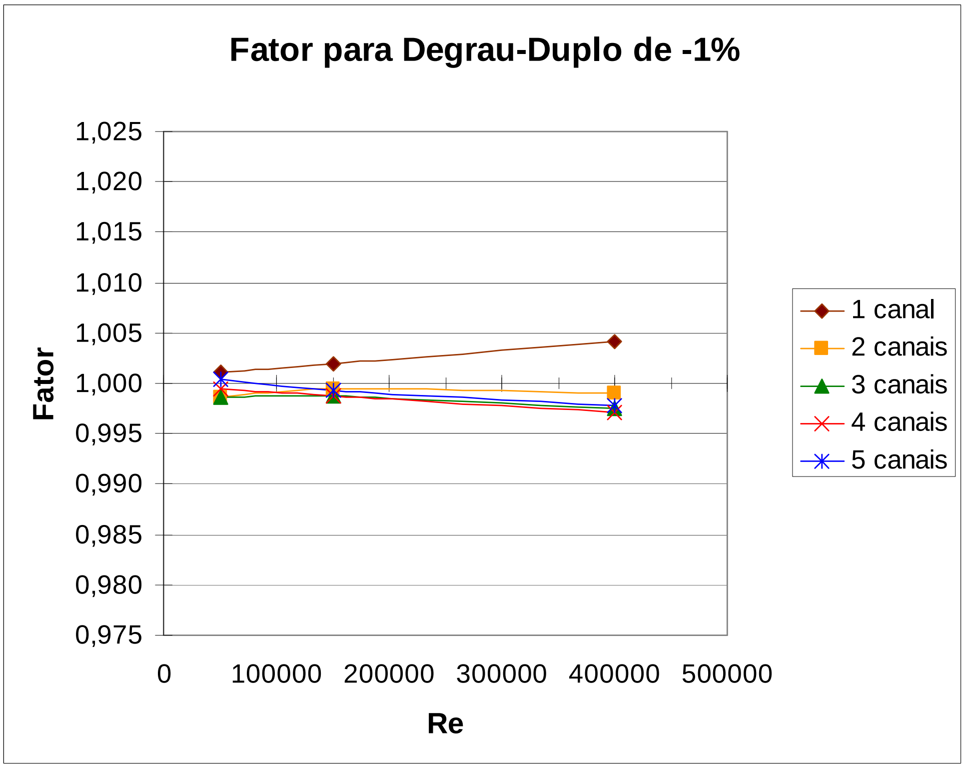

Figura F-6: Fator para o degrau-duplo convergente de –1%.

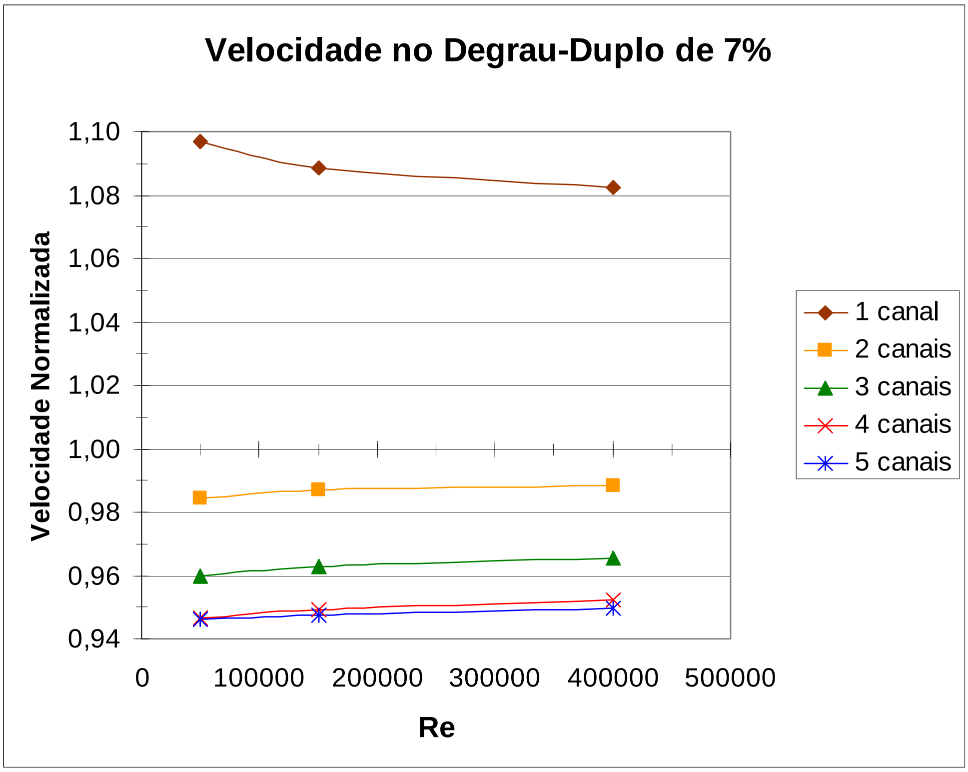

Figura F-7: Velocidade para o degrau-duplo divergente de 7%.

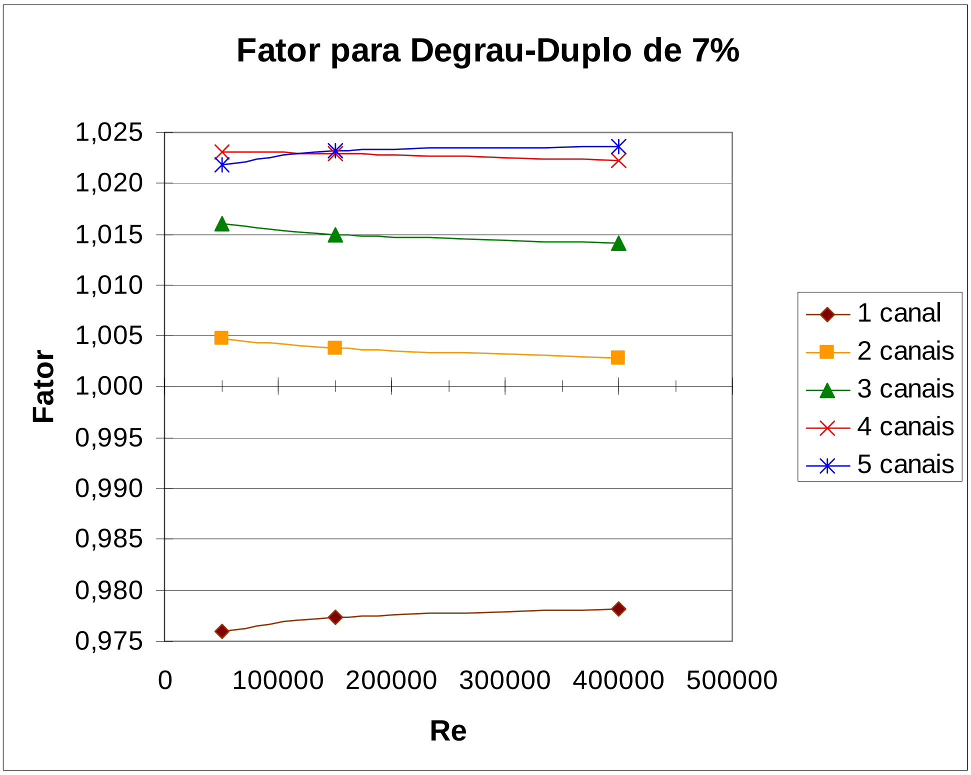

Figura F-8: Fator para o degrau-duplo divergente de 7%.

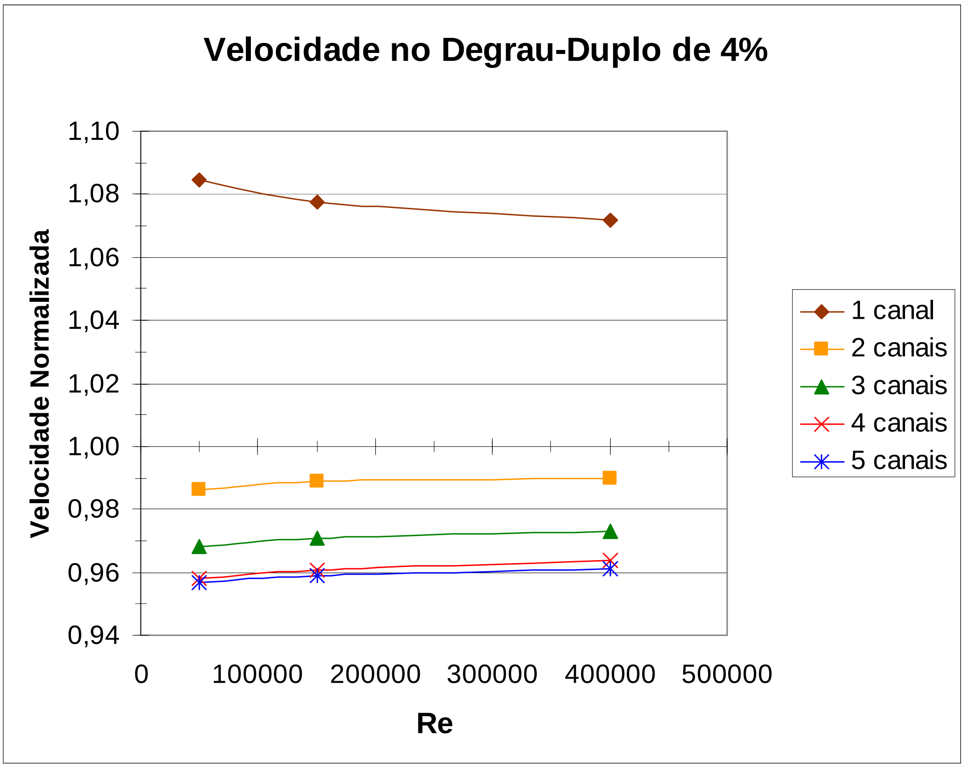

Figura F-9: Velocidade para o degrau-duplo divergente de 4%.

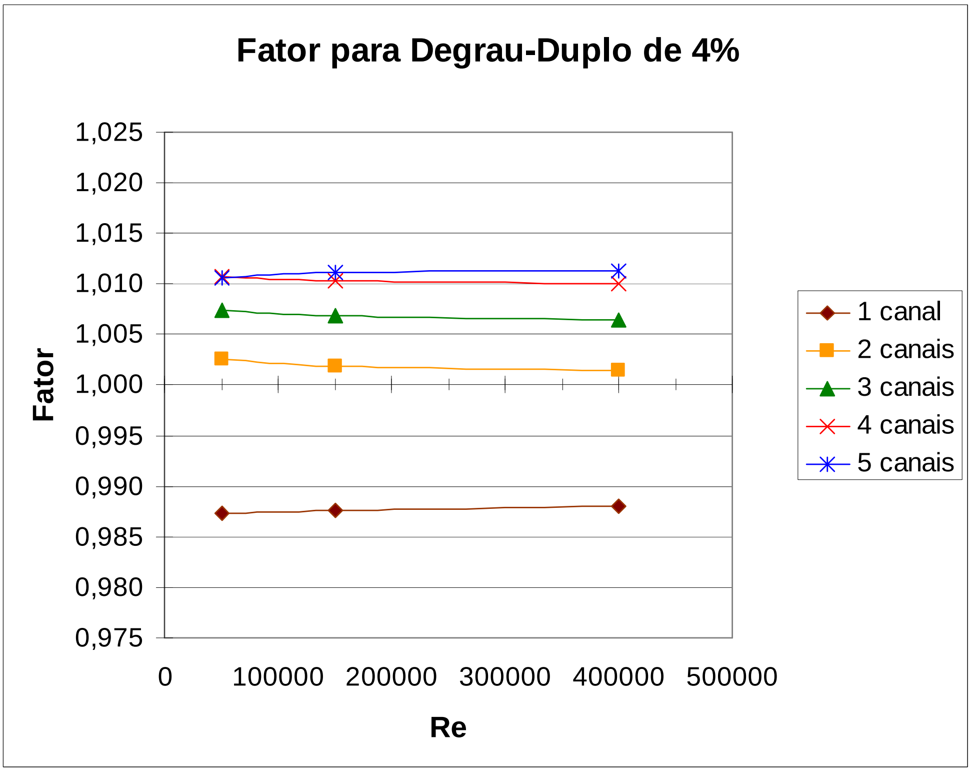

Figura F-10: Fator para o degrau-duplo divergente de 4%.

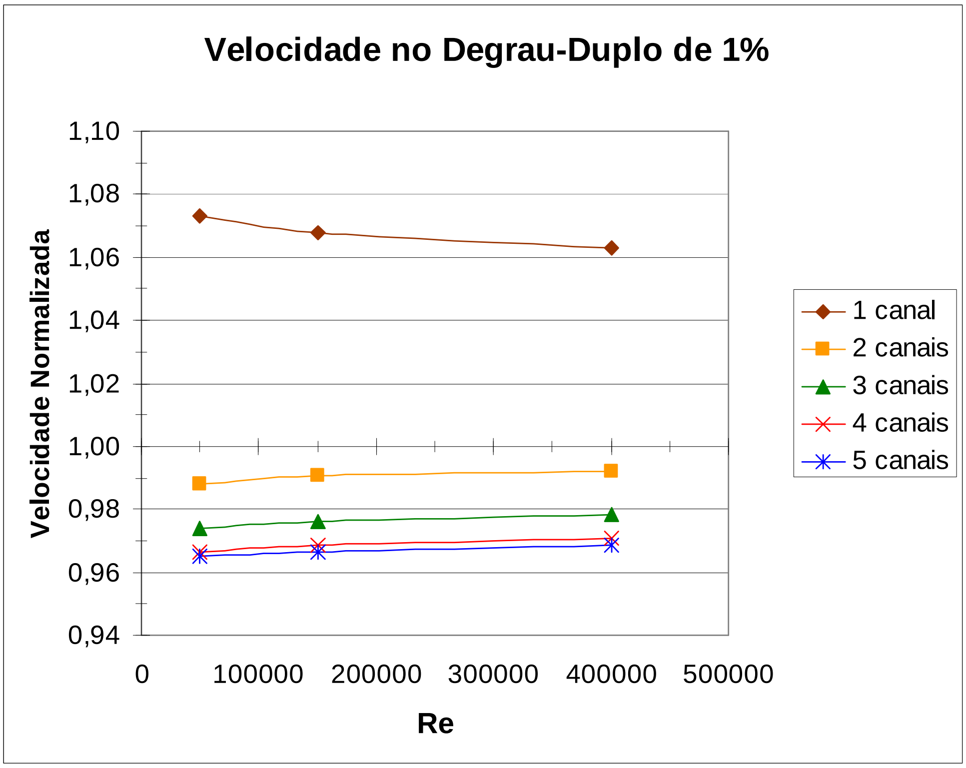

Figura F-11: Velocidade para o degrau-duplo divergente de 1%.

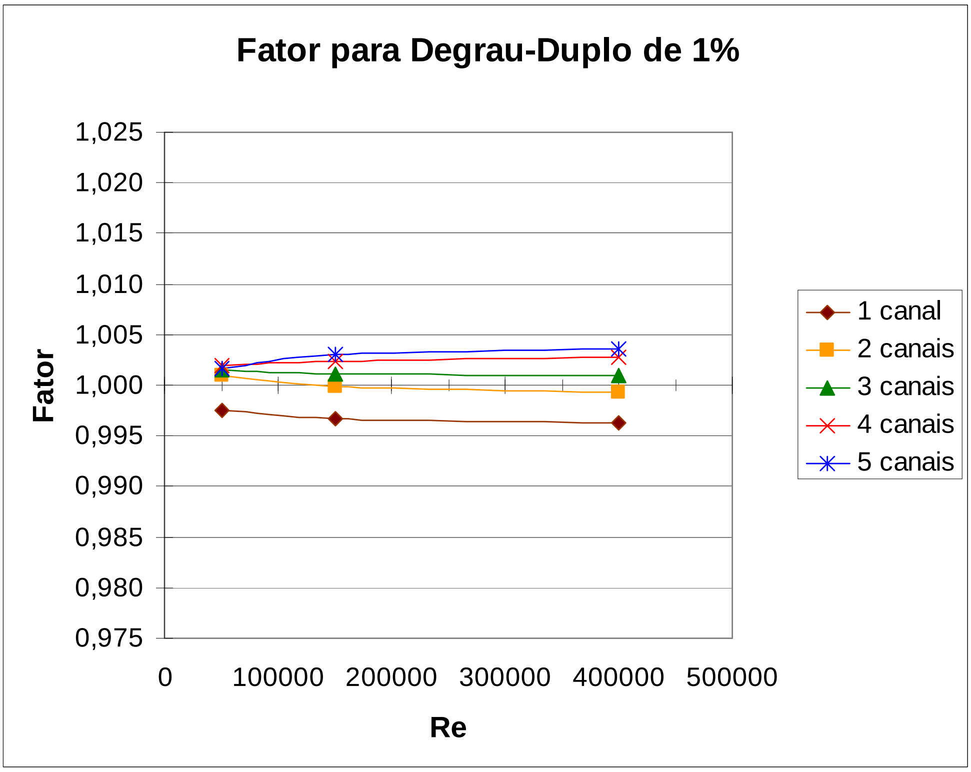

Figura F-12: Fator para o degrau-duplo divergente de 1%.

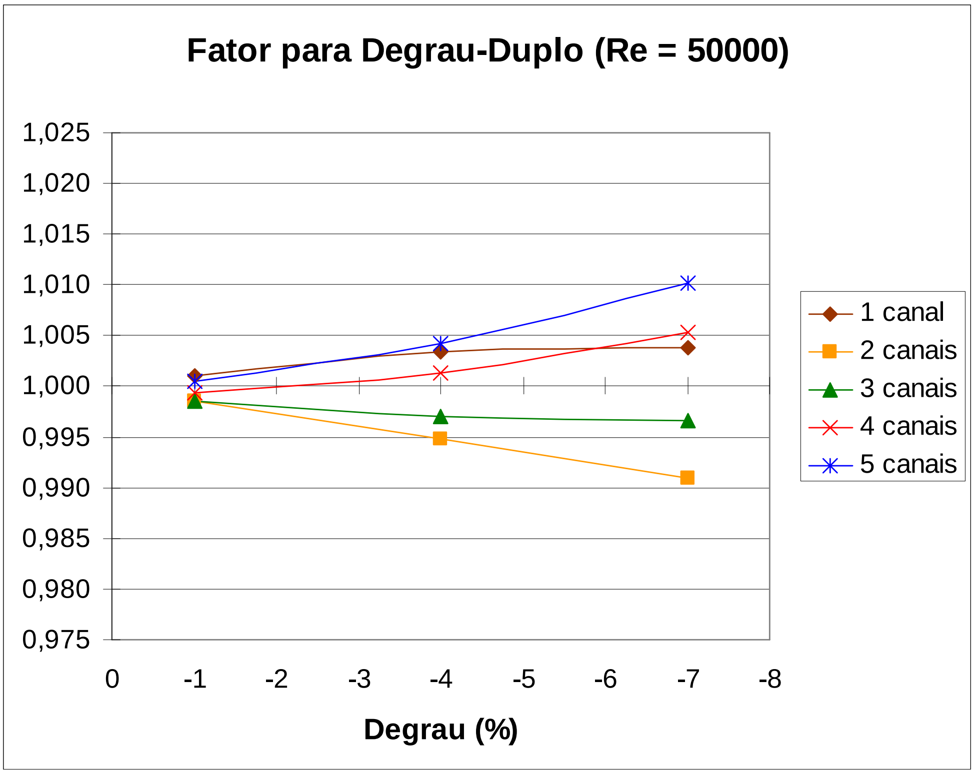

Figura F-13: Fator para o degrau-duplo convergente com Re = 50.000.

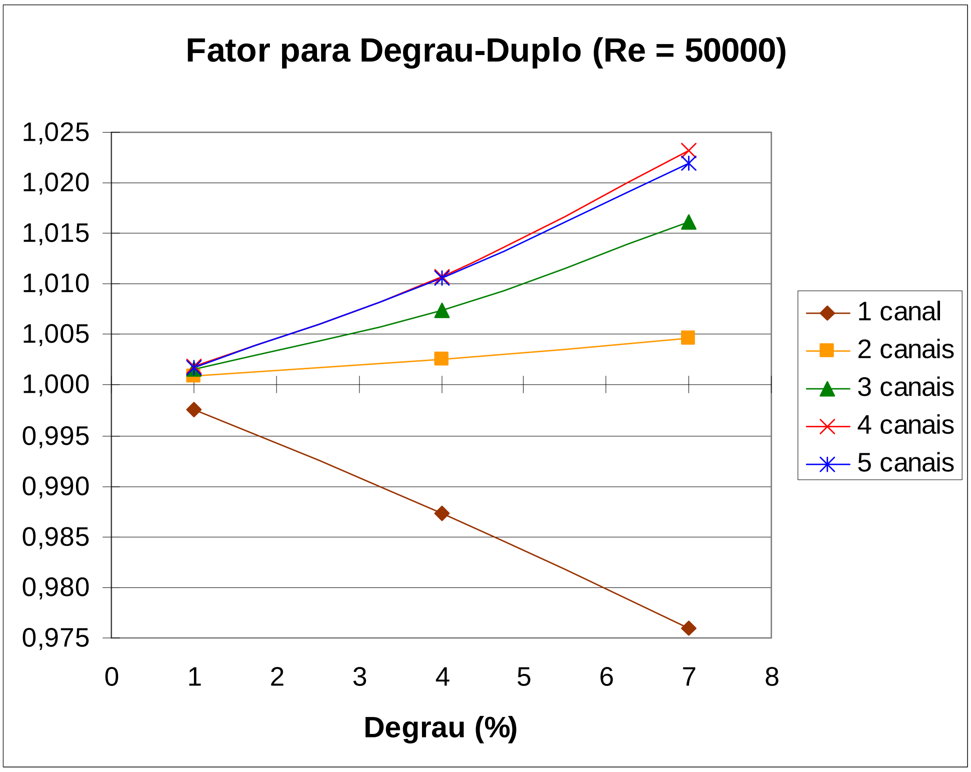

Figura F-14: Fator para o degrau-duplo divergente com Re = 50.000.

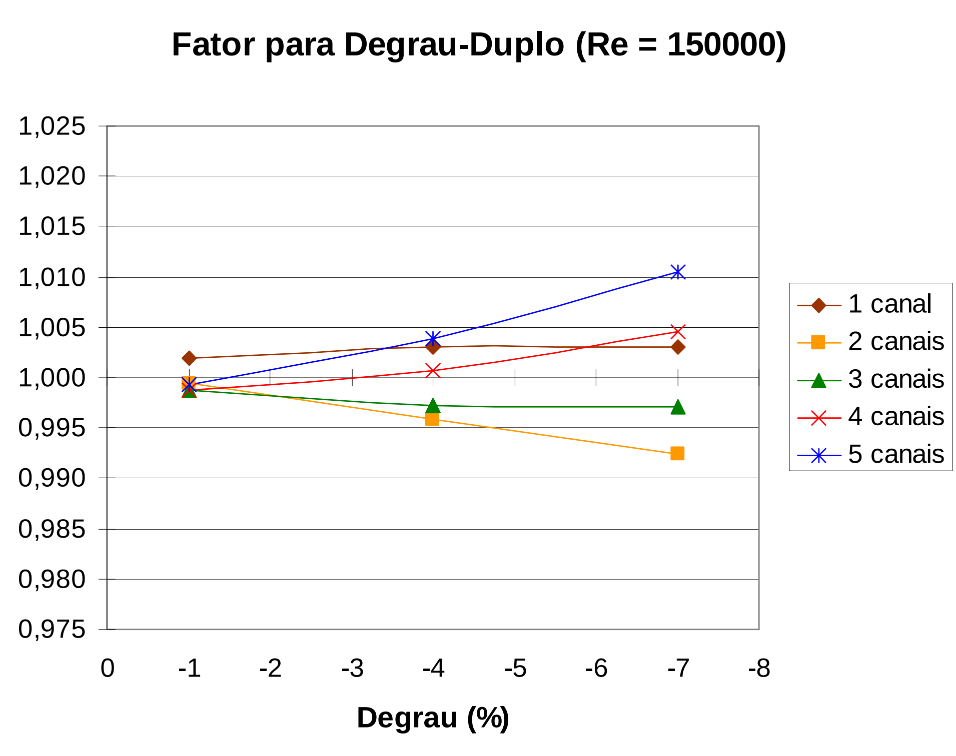

Figura F-15: Fator para o degrau-duplo convergente com Re = 150.000.

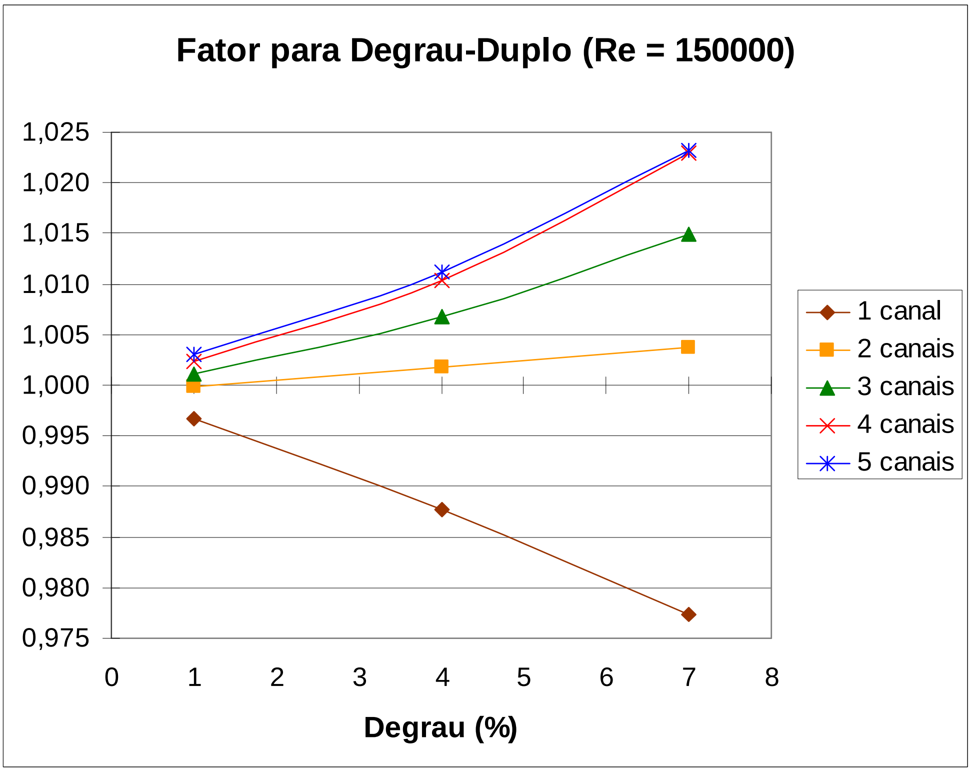

Figura F-16: Fator para o degrau-duplo divergente com Re = 150.000.

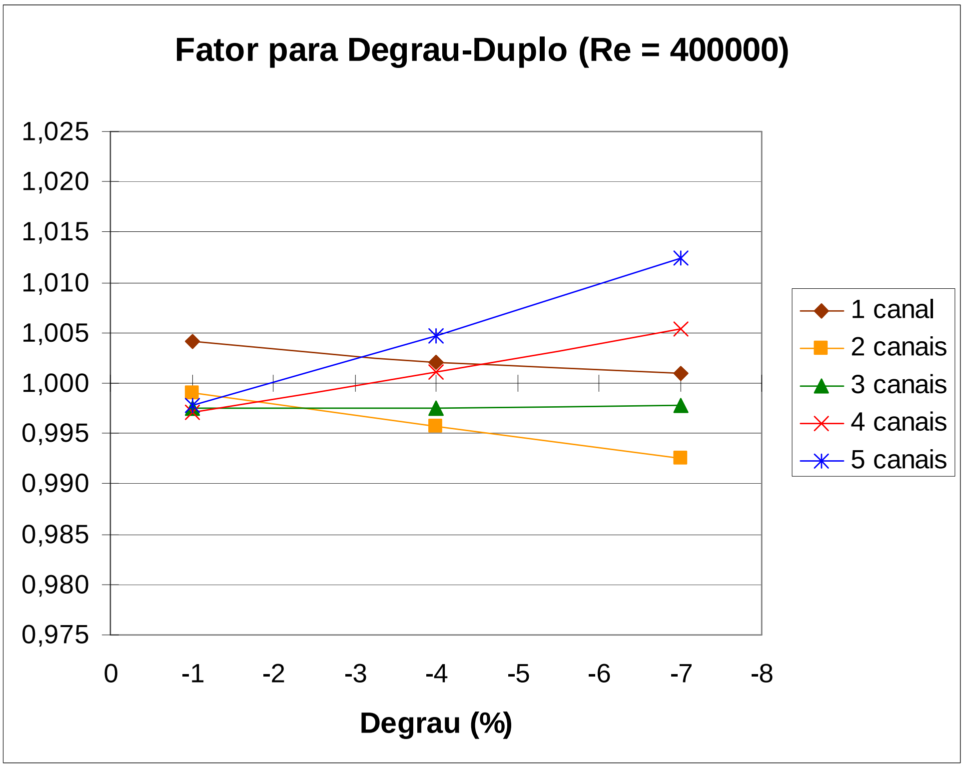

Figura F-17: Fator para o degrau-duplo convergente com Re = 400.000.

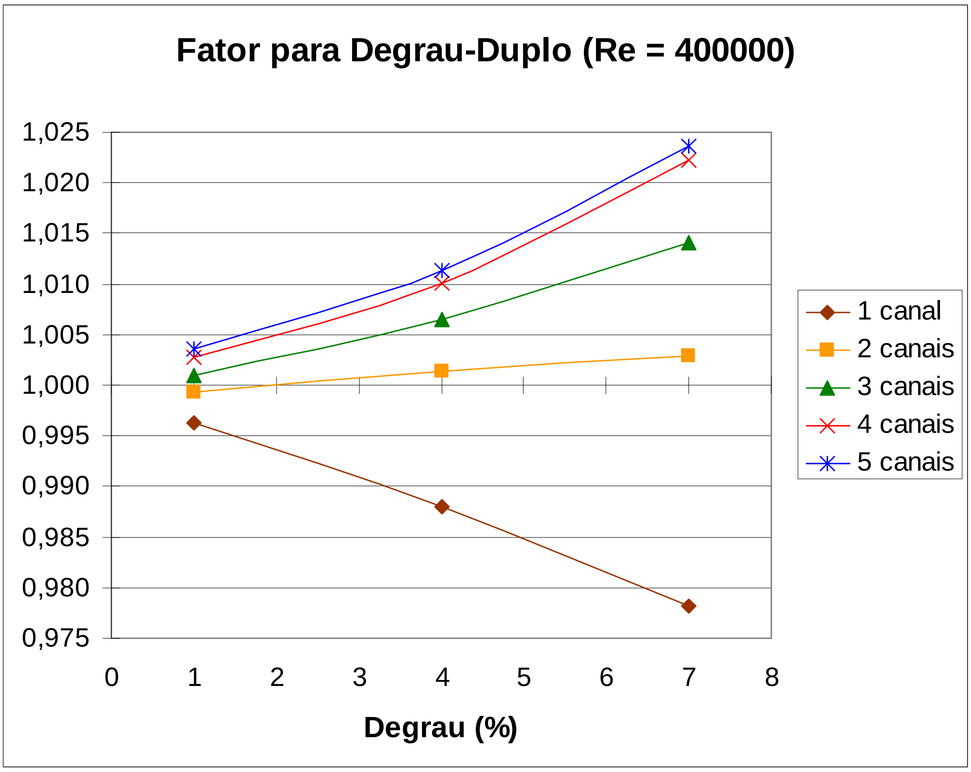

Figura F-18: Fator para o degrau-duplo divergente com Re = 400.000.