Summary: The method of matched asymptotic expansions is applied to the investigation of transitional separation bubbles. The problem-specific Reynolds number is assumed to be large and acts as the primary perturbation parameter. Four subsequent stages can be identified as playing key roles in the characterization of the incipient laminar-turbulent transition process: due to the action of an adverse pressure gradient, a classical laminar boundary layer is forced to separate marginally (I). Taking into account viscous-inviscid interaction then enables the description of localized, predominantly steady, reverse flow regions (II). However, certain conditions (e.g. imposed perturbations) may lead to a finite-time breakdown of the underlying reduced set of equations. The ensuing consideration of even shorter spatio-temporal scales results in the flow being governed by another triple-deck interaction. This model is capable of both resolving the finite-time singularity and reproducing the spike formation (III) that, as known from experimental observations and direct numerical simulations, sets in prior to vortex shedding at the rear of the bubble. Usually, the triple-deck stage again terminates in the form of a finite-time blow-up. The study of this event gives rise to a noninteracting Euler-Prandtl stage (IV) associated with unsteady separation, where the vortex wind-up and shedding process takes place. The focus of the present paper lies on the triple-deck stage III and is twofold: firstly, a comprehensive numerical investigation based on a Chebyshev collocation method is presented. Secondly, a composite asymptotic model for the regularization of the ill-posed Cauchy problem is developed.

MSC:
35Qxx Partial differential equations of mathematical physics and other areas of application
76-XX Fluid mechanics
92-XX Biology and other natural sciences

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Chebyshev collocation method; finite-time blow-up; interaction boundary layer theory; laminar separation bubble; laminar-turbulent transition; unsteady separation

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References:
[13] Alam, M.; Sandham, ND, Direct numerical simulation of ‘short’ laminar separation bubbles with turbulent reattachment, J
Heidelberg Academy of Sciences and Humanities


Fomina, IG, Asymptotic theory of flow past the corners of a contour of a rigid body, Uch Zap TsAGI, 14, 5, 31-38 (1983)


Smith, FT, Concerning dynamic stall, Aeronaut Q, 33, 331-352 (1982)

Brown, SN, Marginal separation of a three-dimensional boundary layer on a line of symmetry, J Fluid Mech, 158, 95-111 (1985) - Zbl 0577.76042

Duck, PW, Three-dimensional marginal separation, J Fluid Mech, 202, 559-575 (1989) - Zbl 0666.76061


Zametaev, VB, Marginal separation in three-dimensional flows, Theor Comput Fluid Dyn, 8, 183-200 (1996) - Zbl 0865.76017


Ryzhov, OS; Smith, FT, Short-length instabilities, breakdown and initial value problems in dynamic stall, Mathematika, 31, 163-177 (1984) - Zbl 0542.76050


Duck, PW, Unsteady three-dimensional marginal separation, including breakdown, J Fluid Mech, 220, 85-98 (1990) - Zbl 0706.76041

Fomin, IG, Asymptotic theory of flow past the corners of a contour of a rigid body, Uch Zap TsAGI, 14, 5, 31-38 (1983)


Goldstein, S., On laminar boundary-layer flow near a position of separation, Q J Mech Appl Math, 1, 43-69 (1948) - Zbl 0033.31701

Landau, LD; Lifshitz, EM, Mechanics of continuous media (1944), Moscow: Gostekhizdat, Moscow


Smith, FT; Daniels, PG, Removal of Goldstein’s singularity at separation, in flow past obstacles in wall layers, J Fluid Mech, 110, 1-37 (1981) - Zbl 0482.76037


Brown, SN, Marginal separation of a three-dimensional boundary layer on a line of symmetry, J Fluid Mech, 158, 95-111 (1985) - Zbl 0577.76042

Duck, PW, Three-dimensional marginal separation, J Fluid Mech, 202, 559-575 (1989) - Zbl 0666.76061


Zametaev, VB, Marginal separation in three-dimensional flows, Theor Comput Fluid Dyn, 8, 183-200 (1996) - Zbl 0865.76017


Ryzhov, OS; Smith, FT, Short-length instabilities, breakdown and initial value problems in dynamic stall, Mathematika, 31, 163-177 (1984) - Zbl 0542.76050


Duck, PW, Unsteady three-dimensional marginal separation, including breakdown, J Fluid Mech, 220, 85-98 (1990) - Zbl 0706.76041

Fomin, IG, Asymptotic theory of flow past the corners of a contour of a rigid body, Uch Zap TsAGI, 14, 5, 31-38 (1983)


Goldstein, S., On laminar boundary-layer flow near a position of separation, Q J Mech Appl Math, 1, 43-69 (1948) - Zbl 0033.31701

Landau, LD; Lifshitz, EM, Mechanics of continuous media (1944), Moscow: Gostekhizdat, Moscow


Smith, FT; Daniels, PG, Removal of Goldstein’s singularity at separation, in flow past obstacles in wall layers, J Fluid Mech, 110, 1-37 (1981) - Zbl 0482.76037


Hsiao, C-T; Pauley, LL, Comparison of the triple deck theory, interactive boundary layer method, and Navier-Stokes computation for marginal separation, Trans ASME J Fluids Eng, 116, 22-28 (1994)


[56] Huebch, WN; Gall, PD; Hamburg, SD; Rothmayer, AP, Dynamic roughness as a means of leading-edge separation flow control, J Aircraft, 49, 1, 108-115 (2012)


[59] Burgraff, OR; Duck, PW; Cebeci, T., Spectral computation of triple-deck flows, Numerical and physical aspects of aerodynamic flows (1982), Berlin: Springer, Berlin

[60] Duck, PW; Burgraff, OR, Spectral solutions for three-dimensional triple-deck flow over surface topography, J Fluid Mech, 162, 1-22 (1986) - Zbl 0587.76056


[81] Blasius, H., Grenzschichten in Flüssigkeiten mit kleiner Reibung, Z Math Phys, 56, 1-37 (1908) - Zbl 39.0803.02


[85] Elliott, JW; Smith, FT; Cowley, SJ, Breakdown of boundary layers: (i) on moving surfaces; (ii) in semi-similar unsteady flow; (iii) in fully unsteady flow, Geophys Astrophys Fluid Dyn, 25, 1-2, 77-138 (1983)


[88] Van Dommelen, LL; Shen, SF, The spontaneous generation of the singularity in a separating laminar boundary layer, J Comput Phys, 38, 2, 125-140 (1980) · Zbl 0452.76035


[90] Cassel, KW; Smith, FT; Walker, JDA, The onset of instability in unsteady boundary layer separation, J Fluid Mech, 315, 223-256 (1996) · Zbl 0953.76024


[93] Gargano, F.; Sammartino, M.; Sciacca, V., High Reynolds number Navier-Stokes solutions and boundary layer separation induced by a rectilinear vortex, Comput Fluids, 52, 73-91 (2011) · Zbl 1271.76066


[95] Brown, SN; Stewartson, K., On similarity solutions of the boundary-layer equations with algebraic decay, J Fluid Mech, 23, 4, 673-687 (1965)


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