

QUVURLARNING MAHALLIY QARSHILIKLARINI MODELASHTIRISHDA SPALART-ALLMARAS MODELINING AHAMIYATI

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<https://doi.org/10.5281/zenodo.20303421>

Kirish. Turbulent oqimlarni modellashtirish zamonaviy gidrodinamika va hisoblash suyuqliklar mexanikasining (CFD) eng muhim yo'nalishlaridan biri hisoblanadi. Sanoat, energetika, aviatsiya va muhandislik kommunikatsiya tizimlarida suyuqlik hamda gaz oqimlari ko'pincha turbulent rejimda harakatlanadi. Bunday oqimlarni aniq hisoblash energiya yo'qotishlarini kamaytirish, qurilmalar samaradorligini oshirish va optimal konstruksiyalar yaratishda muhim ahamiyatga ega. Turbulent oqimlarni tavsiflash uchun Reynolds o'rtalashtirilgan Navye–Stoks (RANS) tenglamalariga asoslangan ko'plab turbulentlik modellari ishlab chiqilgan. Ular orasida Spalart–Allmaras modeli alohida o'rin egallaydi. Ushbu model 1992-yilda Philippe Spalart va Steven Allmaras tomonidan ishlab chiqilgan bo'lib, turbulent yopishqoqlikni aniqlash uchun bitta transport tenglamasidan foydalanishga asoslanadi. Spalart–Allmaras modeli ayniqsa aerodinamik tashqi oqimlar, chegara qatlamlari va yuqori Reynolds sonli oqimlarni hisoblashda samarali hisoblanadi. Modelning asosiy afzalligi uning soddaligi, kam hisoblash resurslari talab qilishi va amaliy masalalarda yetarli aniqlik berishidir. Shu sababli ushbu model ANSYS Fluent, OpenFOAM va boshqa CFD dasturlarida keng qo'llaniladi. Ushbu ishda Spalart–Allmaras turbulentlik modelining nazariy asoslari, asosiy tenglamalari, afzallik va kamchiliklari hamda amaliy qo'llanish sohalari tahlil qilinadi.

$$\frac{\partial \bar{v}}{\partial t} + U_j \frac{\partial \bar{v}}{\partial x_j} = P_w - D_w + \frac{1}{\sigma} \left[\frac{\partial}{\partial x_j} \left((\nu + \bar{\nu}) \frac{\partial \bar{v}}{\partial x_j} \right) + C_{b2} \frac{\partial \bar{v}}{\partial x_i} \frac{\partial \bar{v}}{\partial x_j} \right]. \quad (1)$$

Turbulent yopishqoqlik quyidagicha topiladi:

$$\nu_t = \bar{\nu} f_{v1}, \quad (2)$$

Bu yerda P_w va D_w – turbulentlikning generatsiyasi va dissipatsiyasi hadlari.

Qo'shimcha hadlar quyidagicha yoziladi:

$$P = C_{b1} f_{r1} (1 - f_{i2}) S_{\omega}^2 D_w = \left[C_{w1} f_w - \frac{C_{b1}}{k^2} f_{i2} \right] \left(\frac{\omega}{d} \right)^2, \quad f_{v1} = \frac{\chi^3}{\chi^3 + c_{v1}^3}, \quad f_{v2} = 1 - \frac{\chi}{1 + \chi f_{v1}},$$

$$\chi = \frac{\omega}{\nu}, \quad S_{\omega} = \Omega + \frac{f_{v2}}{k^2 d^2}, \quad \Omega = \sqrt{2W_{ij}W_{ij}}, \quad f_w = g \left[\frac{1 + c_{w3}^6}{g^6 + c_{w3}^6} \right]^{1/6}, \quad g = r + c_{w2} (r^6 - r),$$

$$r = \frac{\omega}{S_{\omega}^2 d^2}, \quad f_{i2} = c_{i3} \exp(-c_{i4} \chi^2), \quad W^2 = 2W_{ij}W_{ij}, \quad S^2 = 2S_{ij}S_{ij}, \quad S_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right),$$

$$f_{r1} = \frac{2r'(1 + c_{r1})}{1 + r'} \left(1 - c_{r3} \arctan(c_{r2} \bar{r}) \sqrt{a^2 + b^2} \right) - c_{r1}, \quad \bar{r} = \frac{2\Omega_{ik} S_{jk}}{D^4} \left(\frac{\partial S_{ij}}{\partial t} + u_k \frac{\partial S_{ij}}{\partial x_k} \right),$$

$$D^2 = \frac{1}{2}(S^2 + W^2), \quad r' = S / w$$

; bu yerda W_{ij} – uyurma tenzori; d – devorgacha bo'lgan eng yaqin masofa. Model o'zgarmlari quyidagicha qabul qilinadi:

$$c_{b1} = 0.01355, c_{b2} = 0.622, c_{w2} = 0.3, c_{w3} = 2, c_{v1} = 7.1, c_{i3} = 1.2, c_{i4} = 0.5,$$

$$c_{w1} = \frac{c_{b1}}{k^2} + \frac{1 + c_{b2}}{\sigma}, c_{r2} = 12, c_{r1} = c_{r3} = 1, \sigma = 2/3, K = 0.41.$$

Silindrik koordinatalarda (1) tenglama quyidagicha yoziladi:

$$\begin{aligned} \frac{\partial \bar{v}}{\partial t} + V_z \frac{\partial \bar{v}}{\partial z} + V_r \frac{\partial \bar{v}}{\partial r} = P_w - \\ - D_w + \frac{1}{\sigma} \left[\frac{\partial}{\partial z} \left((v + \bar{v}) \frac{\partial \bar{v}}{\partial z} \right) + \frac{\partial}{r \partial r} \left((v + \bar{v}) \frac{\partial r \bar{v}}{r \partial r} \right) + C_{b2} \frac{\partial \bar{v}}{\partial r} \frac{\partial r \bar{v}}{r \partial r} \right] \end{aligned} \quad (3)$$

Xulosa. Spalart–Allmaras turbulentslik modeli RANS tenglamalariga asoslangan eng samarali va sodda modellashtirish usullaridan biri hisoblanadi. Modelning asosiy afzalligi turbulent yopishqoqlikni aniqlash uchun faqat bitta transport tenglamasidan foydalanishidir. Bu esa hisoblash jarayonini tezlashtiradi va kam hisoblash resurslari talab qilinishini ta'minlaydi. Mazkur model ayniqsa aerodinamik tashqi oqimlar, chegara qatlamlari hamda samolyot va avtomobil aerodinamikasini hisoblashda keng qo'llaniladi. Spalart–Allmaras modeli boshqa ko'p tenglamali turbulentslik modellariga nisbatan soddaroq bo'lsa-da, ko'plab amaliy masalalarda yetarli aniqlik beradi. Shu bilan birga, modelning ayrim cheklovlari ham mavjud bo'lib, kuchli ajraluvchi, aylanishli va anizotrop turbulent oqimlarda aniqlik pasayishi mumkin. Biroq hisoblash tezligi va amaliy qulayligi sababli ushbu model zamonaviy CFD dasturlarida keng qo'llaniladigan asosiy turbulentslik modellaridan biri bo'lib qolmoqda.

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