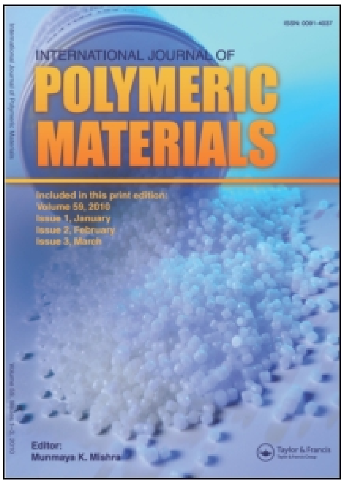

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K. Adámek[a]
[a] VÚTS-Research Institute for Textile Machines, Liberec, Czech Republic

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Numerical Modelling of Air Flow in Air Jet Weaving System

K. ADÁMEK

VÚTS-Research Institute for Textile Machines, U Jezu 4, 46119 Liberec, Czech Republic

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Paper summarizes the first results of two-dimensional (2D) numerically modelled expansion and flow of compressible and non-viscous gas in typical parts of air jet weaving system: in main nozzle designed as an ejector with various shapes of the mixing zone, in relay (auxiliary) nozzle with substantial flow separation in the rash flow bend directly before the nozzle outlet and the influence of the shape of the reed dent edges on the free stream reflection and penetration through reed gaps along a real "porous" wall.

Used Euler's equations are solved by a Finite Volumes Method (FVM) with automatic mesh generation and optimization of unstructured triangle mesh. Graphical results show 2D isolines of all state values of the gas, further Mach number, entropy and velocity vectors. 1D profiles of all quantities along choosen cross-section or surface can be obtained, too. They give to the designer a large and quick review about the problem. The coincidence with experiment, measuring and real weaving tests is very good. The advantage of the PC using consists in the very quick, simple and user-friendly operation.

Keywords: Air jet weaving system; main nozzle; auxiliary nozzle; profile reed; flow field; numerical modelling of air flow; FVM (Finite Volume Method)

USED METHOD

The used software [1] operates on a personal computer. It permits numerical modelling of compressible transonic and non-viscous flows in two-dimensional (2D) areas. Physical model is described by system of Euler's equations and solved by using of finite volumen method (FVM). Discretization of area is made by non-structured triangle mesh [2], automatically generated and optimized.

Pre-processor enables an user-friendly geometry definition of solved area, automatic optimal mesh generation with possible remeshing and stretching, according to the concrete flowfield and definition of thermodynamic, boundary and initial conditions.

Solver uses optionally and 2nd order scheme of the calculation to get the higher precision of precalculated results. The convergence of used numerical method is indicated by the residuum value. When strong vortices appear in the solved area (for example in consequence of its shape), the really stable solution sometimes cannot be reached because the used mathematical model is not destined for whirled flows.

Post-processor gives simply various graphics results in 2D isolines of state values (pressure, temperature, density) and these of velocity, Mach number and entropy, too, further velocity vectors and any demanded 1D profile of all quantities along choosen cross-profile or surface. Exporting the results in any spreadsheet it is possible to express many other needed physical quantities for example components [wx, wy] and direction [arctan(wy/wx)] of the velocity vector, air drag (proportional to [ro • w^2]), flow density [ro * w], vorticity [$(dwy/dx-dwx/dy)/2$] *etc.*

AREA OF APPLICATION

Air jet weaving system, developed in 50's in VÚTS Liberec and spreaded in the whole world, allows the highest weaving performance. As an example, modern air jet loom can operate at 1500 rpm. When the weft picking time is of about 50 per cent of each working period, then for the standard cloth width 1.9 m the medium picking velocity reaches the value of 85 m/s (300 km/h) approx. In addition, the velocity field arises again in each working period, because it is periodically abolished during beat-up motion.

By contemporary development of fundamental parts of air picking system there studying the internal flow and expansion of compressed air in weaving nozzles – both the main and auxiliary ones – and the free stream propagation in the atmosphere after nozzle outlet, too with interaction between the stream and complicated reed wall – partial reflection and penetration of the flow. Received velocity (dynamic pressure) field transports the textile yarn – the linear body with very small and bad defined cross dimensions and slight bend stiffness – to create the cloth.

PRESENTATION OF RESULTS

Numerical modelling gives more information about the velocity/pressure distribution in observed areas of air jet weaving system: the internal flow of expanding air together with the free stream propagation in the atmosphere after nozzle outlet.

In general, two types of weaving nozzles are used:

- the main nozzle designed as an ejector overcomes the resistance of weft premeasured and prepared on the feeder drum, accelerates and transports it into the picking channel,
- auxiliary (or relay) nozzles designed simply as a hollow needle with orifice in lateral wall are located in regular pitches along the picking channel made from thin metallic sheets positioned across to the flow direction, and keep the values of the air flow velocity at level needed for quick and sure weft transport.

MAIN NOZZLE

Using overcritical pressure ratio, in mixing zone of an ejector arises a shock waves area. The nozzle aggressivity and ability of acceleration towards transported textile yarn is partially given by existence, position and intensity of this area [3, 4]. Numerical modelling permit simple observation of shock waves intensity and position in dependence on the shape of the mixing tube. The influence of the mixing tube shape of an ejector and intensity of shock waves in the flow show Figure 1. All dimensions of ejectors are identical, the output diameter is changed only. Thermodynamic conditions are identical, too, used pressure ratio is overcritical of $p/p0 = 1/7$.

On the Figure 1a there is shown considerable shock wave area with non-homogeneous velocity field. On the Figure 1b there is one strong shock in the step only. This design is better for the stable weft position in flow and for its insertion more reliable – the maximum flow velocity

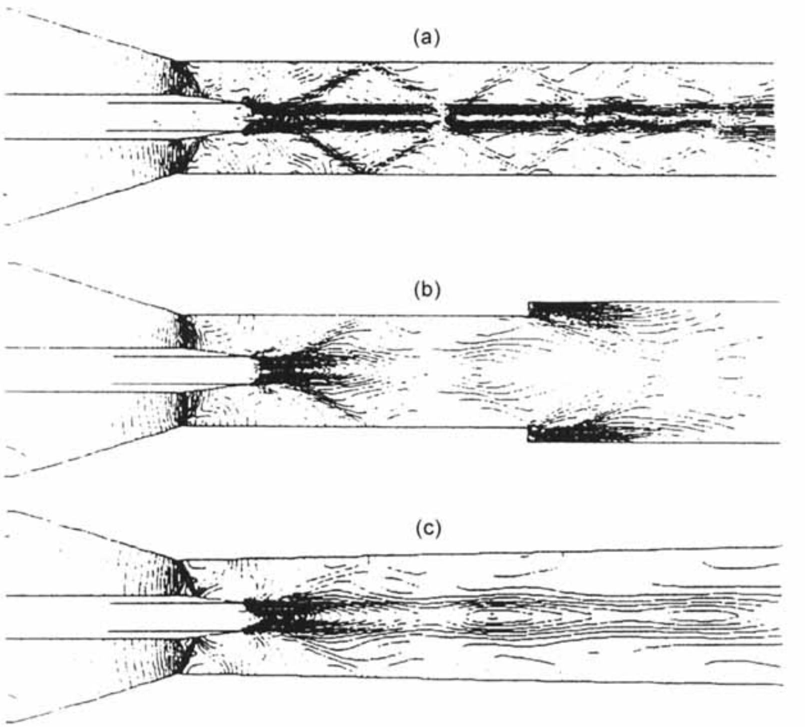

FIGURE 1 Velocity field of ejectors, (a) cylindrical; (b) stepped; (c) divergent mixing tube.

operates on the weft tip, the very flexible weft yarn is pulled out, not pushed like after Figure 1a. The idea was verified by actual weaving tests. The Figure 1c shows the divergent shape of the mixing tube which complies better with conditions for the overcritical expansion. The flow field with higher velocity values and feeble shock waves was reached only.

The lengthways velocity profiles along the axis of the mixing tube lengths, corresponding to the Figure 1, shows Figure 2.

Next Figure 3 shows a possible evaluation of results from Figure 1a – in different scales there are values of u – velocity, ro – density, (ro$^{*}w^2$) – expression proportional to the elementary air drag and summary drag from the ejector beginning.

The Figure 4 shows the detail of the outlet of central tube for another design of ejector (for example with convergent mixing tube or

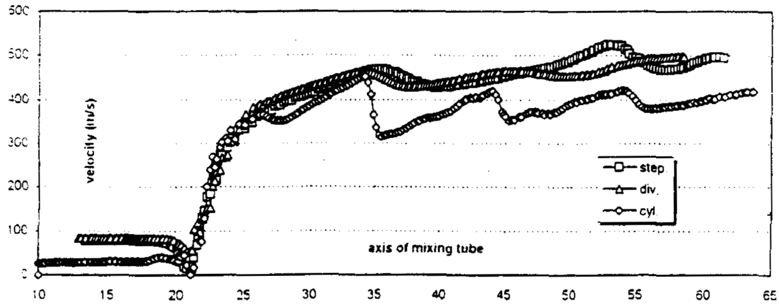

FIGURE 2 Velocity profiles of ejectors from Figure 1.

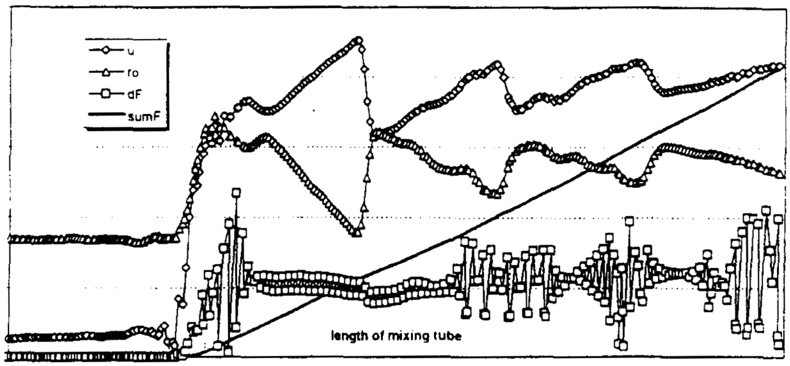

FIGURE 3 Profiles of several flow quantities (for ejector form Fig. 1a).

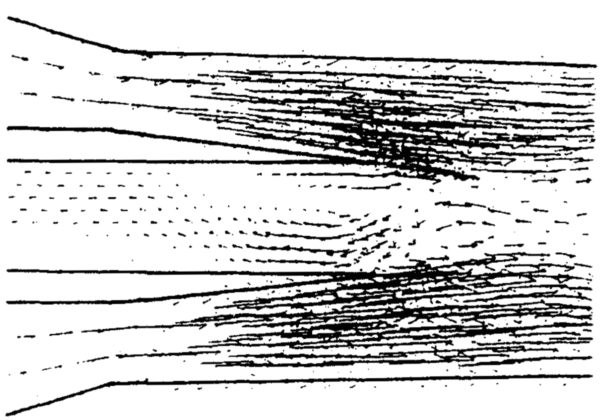

FIGURE 4 Backflow in the middle tube of an ejector.

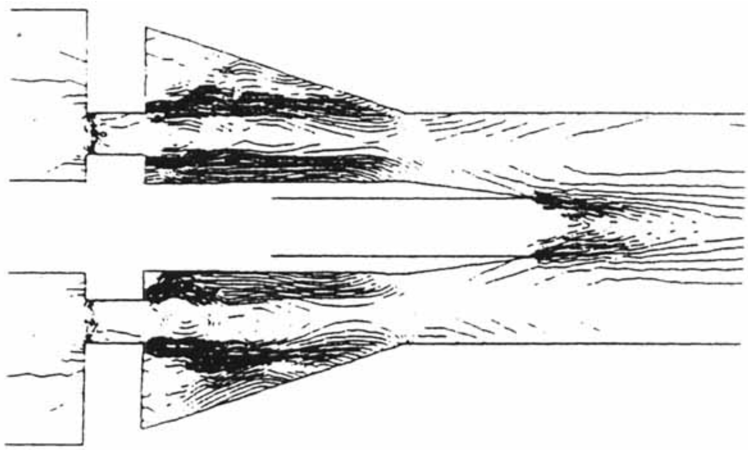

FIGURE 5 Detail of double expansion in the entry part of ejector.

with central tube located more to the left side of the design or with increased entry of compressed air *etc*.). The mixing tube is here "overfilled" by the flow, some part of the air is flowing back and the necessary suction effect is none. This kind of ejector is not suitable for practical weaving, the broken weft cannot be sucked.

So called "classical" design of main jet is presented on Figure 5. In comparison with previous modern design the expansion is "divided" here into two parts. The first part of expansion is realized through cross wall at the entry, without contact to accelerated and transported weft, located in the middle tube. Only the second part of the expansion has an important influence on the weft. This type of main nozzle does not reach the highest weaving performance but at the same time it handles gently the weft. It is important for weaving materials with small firmness, as for example spun yarns. On the other side, with previous type of main nozzle we can reach the highest weaving performance but extreme tensile strength needs special materials, as for example polyester rayons.

RELAY NOZZLES

System of auxiliary nozzles situated along the reed channel covers the flow losses given by free flows dissipation. The flow inside auxiliary nozzle is characterized with its sharp bend directly before the outlet.

The expressive stream separation and contraction in classical auxiliary nozzle after Figure 6a affects on the unstable free stream direction when air pressure in the supply is reset.

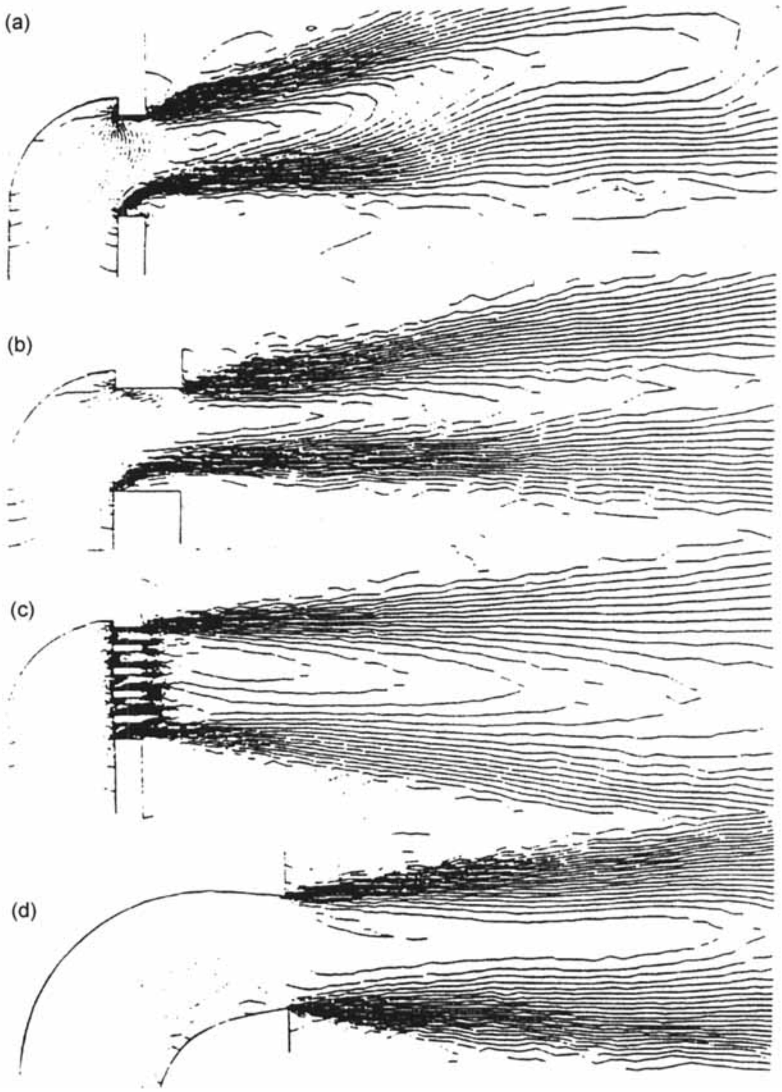

FIGURE 6 Flow in auxiliary nozzles: (a) simple wall thickness; (b) double wall thickness; (c) multi-orifice; (d) with inner channel.

In the double outlet wall thickness after Figure 6b there is the flow better guided, the free stream direction is more stable. The same positive effect has "shower" relay nozzle with several small orifices, see Figure 6c. The elementary flows create quickly one common flow, practically independent on the outlet shape, as verified with measuring [5, 6]. A special case is the "channel" relay nozzle with inner channel after Figure 6d. Its fluent bend before the nozzle outlet [7, 8] is designed such a way that there is no flow separation in it and the value of velocity in the outlet cross-section is approximately constant. It is ideal case, the flow is well guided and the free stream direction is independent on the air pressure in the supply. The theoretical presumptions were verified with measuring of serial of ceramic nozzles with inner channel.

Note: The subsonic pressure ratio of $p/p0 = 0,7$ was assigned here, only, influence of overcritical pressure ratios will be presented during the lecture.

FLOW INTERACTION WITH REED WALL

Further it was modelled the complicated interaction of the constant free flow with the reed wall created by system of reed dents. The shape of reed dent edges influences on the reflection of the free stream from the reed wall and on the penetration through reed gaps [9]. They were modelled three angular shapes of reed dent edges (rectangular, convergent and divergent) and three rounded shapes (on the left, right and both edges of each dent).

Typical interaction of a large constant flow (velocity of 100 m/s) with a reed wall (inclined of 5 degrees to the flow) shows Figure 7 – the velocity isolines on the left side, the vectors field on the right side. The flowfield is similar for all modelled dent shapes (here is presented the convergent shape, only). The large main flow is disturbed a little, only – till the distance of the dent thickness approx. In each gap there is the flow separation accompanied with a vortex. The vortex length is of about 25% of the whole gap length for all right-angled shapes of reed dents and of about 75% for all rounded shapes of reed dents. The flow penetration is of 5% for convergent reed dent shape and from 9% to 11% for all other reed dent shapes (percentage of the whole same flow, comming into the same control area).

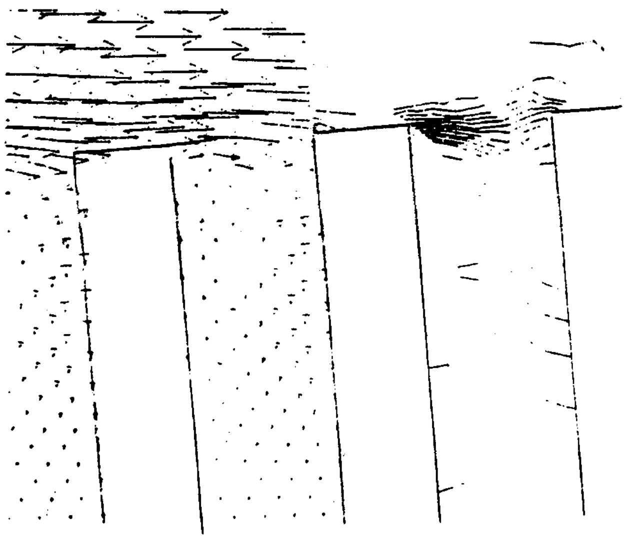

FIGURE 7 Flow reflection and penetration (convergent reed dents edges).

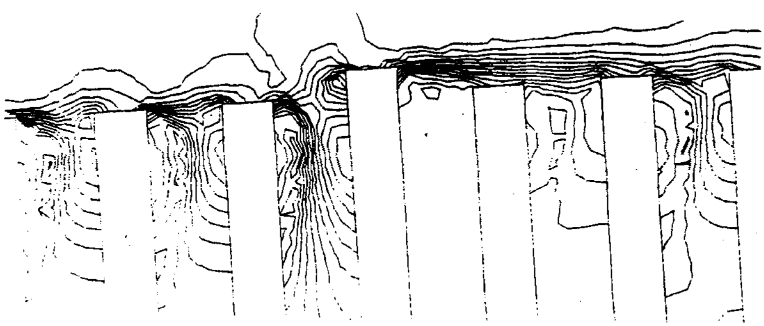

FIGURE 8 Influence of wrong position of one reed dent on velocity field along reed wall.

The very interesting situation of the velocity field, when the position of one of reed dents is wrong, shows Figure 8:

- in the first gap there is a standard flow,
- in the second gap is a greater flow (next reed dent is pushed out from the line),
- in the third gap there is a small backflow,

– in the fourth gap there is a small flow in the correct direction,
– in the fifth and next gaps there is a standard flow again.

CONCLUSIONS

The aim of presented FVM application is concentrated on three points:

(1) the form, position and intensity of the shock wave area, arising in the mixing tube of an ejector during the expansion from overcritical pressure ratio,
(2) the flow field in relay nozzles with considerable flow separation and free streams from relay nozzle outlet,
(3) interaction of the flow with reed wall, the flow reflection and penetration.

The used calculus replace expensive, long-term and sometimes impossible experiments as measuring, visualization *etc.* They allow to evaluate more variants of inner nozzle shape before the designing. The coincidence of numerical solution with experiment or real weaving test is very good [3, 9]. Presented simple software gives very good qualitative imagination about the problem – it is a preference of finite elements methods in general.

Presented application of numerical modelling of two-dimensional compressible inviscid flows gives several direct and quick results for practical use by designing of weaving air nozzles:

– good imagination about the whole 2D flow (the state values of gas, position, intensity and form of shock waves) in many designed variants,
– entry data for following calculation of equation of textile yarn motion in precalculated velocity/density field,
– setting conditions for reliable nozzle operation in the weaving mill, as for example the sure suction of ejector.

Of course, real flows are more complicated furthermore the stream expansion it should be take into account the flow viscosity and turbulence, too. When strong vortices appear in the solved area (for example in consequence of its shape), the really stable solution sometimes cannot be reached here.

The complex solution needs more powerfull software and hardware, so the presented results are simplier than these ones obtained by using a three-dimensional software, used for optimization of velocity field in real profile channel of a reed.

Several other problems are solved, like for example:

- impact flow in a drying/finishing textile machine,
- flow around a dried and transported cylinder in food industry,
- flow in pneumatic tuck-in device of a weaving machine,
- pressure/velocity field in melt-blown technology (production of PoP thermal insulation),
- velocity/temperature field in door-screen *etc.*

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