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Optimization of Coal Particle Flow Patterns in Low N0x Burners

Quarterly Report
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INTRODUCTION

The proposed research is directed at evaluating the effect of flame aerodynamics on NO_x emissions from coal fired burners in a systematic manner. This fundamental research includes both experimental and modeling efforts being performed at the University of Arizona in collaboration with Purdue University. The objective of this effort is to develop rational design tools for optimizing low NO_x burners to the kinetic emissions limit (below 0.2 lb./MMBTU). Experimental studies include both cold and hot flow evaluations of the following parameters: flame holder geometry, secondary air swirl, primary and secondary inlet air velocity, coal concentration in the primary air and coal particle size distribution. Hot flow experiments will also evaluate the effect of wall temperature on burner performance.

Cold flow studies will be conducted with surrogate particles as well as pulverized coal. The cold flow furnace will be similar in size and geometry to the hot-flow furnace but will be designed to use a laser Doppler velocimeter/phase Doppler particle size analyzer. The results of these studies will be used to predict particle trajectories in the hot-flow furnace as well as to estimate the effect of flame holder geometry on furnace flow field. The hot-flow experiments will be conducted in a novel near-flame down-flow pulverized coal furnace. The furnace will be equipped with externally heated walls. Both reactors will be sized to minimize wall effects on particle flow fields.

The cold-flow results will be compared with Fluent computation fluid dynamics model predictions and correlated with the hot-flow results with the overall goal of providing insight for novel low NO_x burner geometry's.

PROGRESS FOR THIS QUARTER

The major activities conducted during the first quarter of the project included contract finalization, development and approval of an inter-college collaboration agreement between the University of Arizona and Purdue University, project staffing and preliminary design of the hot and cold flow furnaces. As the hot flow experiments are being conducted by the U of A and the majority of the cold flow studies and all Fluent modeling tasks are being conducted at Purdue, the progress for each institution are described separately below.

UNIVERSITY OF ARIZONA Hot Flow Furnace

Mass and energy balance calculations were made to size the pulverized coal down flow furnace. This new furnace is nominally rated at 17 kW (2 kg/hr coal), but is sized to burn up to 6 pounds per hour (2.7 kg/hr). Major design features of the furnace include external heating of the walls, sampling access and visual windows/ports for laser analysis. Externally heating the walls will produce an environment inside the furnace similar to a commercial scale unit with multiple burners where the gas stream from one burner influences those nearby. A reactor diameter of 18" was chosen to minimize particle impingement on the reactor walls that is typical of smaller laminar flow furnaces 3 to 6 inches in diameter.

Several gas-fired heater configurations and electric resistance heater designs were evaluated. Gas-fired designs included multiple firing tubes embedded in the walls and a gas-fired annulus. These designs were not practical due to the heating area requirements of the large diameter furnace, the need for high temperature thermally conductive, but non-porous refractory materials separating the gas heater and the reaction zone, and the weights of these materials. A three-zone design with electric resistance heaters embedded in the insulated furnace walls was ultimately chosen for the final furnace design. This arrangement provides uniform heating down the furnace, allows the use of light-weight insulating refractory, and provides the most versatility with respect to future modifications/adjustments of the sample ports as the insulating board can be easily machined compared to silicon carbide or Kaocrete type materials.

The primary and secondary air streams were sized based on a maximum coal firing rate of 6 pounds per hour (2.7 kg/hr) and an air to coal stochiometric ratio of 1. Based on these parameters the maximum combustion air requirements for the furnace is 15.3 SCFM. The primary air (transport air) flow of 3 SCFM is based on 20% of the total combustion air. The secondary air flow is 12.3 SCFM. These flow rates were used to determine the burner size. A axial jet design was selected for this project. The burner consists of a fuel injection tube surrounded by the secondary air. The dual flow arrangement produces recirculation zones downstream of the burner which depend on velocity of the primary and secondary air flows and degree of secondary air swirl. Utilizing ½" and 1" stainless steel pipe for the fuel nozzle secondary air tube produces gas velocities of 31 fps and 59 fps, respectively. At preheated air temperatures of 250°F, these velocities increase to 42 and 77 fps.

As previously mentioned, a furnace diameter of 18" was selected to minimize wall effects on particle trajectories. Based on this diameter, complete combustion at stochiometric conditions and an average combustion gas temperature of 1500K, the superficial gas velocity of the combustion products is approximately 0.8 fps. Thus a three foot "hot section" would have a mean residence time of 3.7 seconds. The electrically heated section will be followed by a 2-3 foot cool section to maximize coal burnout before the combustion products exit the furnace. The furnace exhaust will be routed directly to the building exhaust system.

Second Quarter Goals

Tasks to be completed during the second quarter include finalizing the furnace design and design and selection of the external heater controls. Temperature profile calculations will also be performed for the furnace. Cost estimates for the furnace components will be obtained and the materials ordered. Burner design will continue.

Cold Flow Studies at Purdue University

Jennifer Sinclair, School of Chemical Engineering

In this first quarter of the first year of the research plan, we focused our efforts in two areas:

1. Design of the experimental flow chamber
2. Simulations of single phase flow patterns in the proposed design

Design of the Experimental Flow Chamber

Figure 1 depicts the schematic of our proposed system. The nozzle is 0.5" I.D. with a length to diameter ratio of 100. This long nozzle length is necessary to ensure uniform flow of particles into the test chamber. The flow chamber is 18" square and is to be constructed of optical grade pyrex for the laser Doppler velocimeter/phase Doppler anemometer measurements. The chamber length is 3'. These dimensions coordinate well with the proposed design for the hot flow studies at the University of Arizona. The compressed air will be house air in the chemical engineering building at Purdue. The hopper will be pressurized to avoid bubbling or reverse flow of particles back into the hopper. When bimodal particle systems are investigated, two hoppers will be used.

The particles to be used will be monosized, spherical glass beads. We have contacted several manufacturers and these particles are very costly (e.g., Duke Scientific, $145/gram). Hence we will collect particles at the bottom of the chamber for recycle. The first particle size to be investigated will coincide with the coal particle size to be used at the University of Arizona. This coal has a mean particle diameter of 51 microns. When the effect of polydispersity is investigated, we will sieve the particle mixtures for recycle. The seed particles will be 1-2 micron glass beads.

Simulations of Single Phase Flow in the Proposed Design

Figures 2 through 10 depict the single phase flow patterns we expect to see in our proposed chamber. In all of the figures the inlet jet velocity is 15 m/s. Figures 2, 3 and 4 present a stream function plot, velocity contour plot, and a turbulence intensity plot employing the k-ε turbulence closure model and a 120 x 80 non-uniform grid (Figure 11). Figure 2 shows the presence of recirculation in the chamber. From Figure 3 it is evident that the magnitude of the velocity associated with this recirculation zone is one order of magnitude less than the centerline jet velocity at the same distance downstream from the nozzle. Hence the effect of the side walls on the flow behavior of the jet is minimal for our proposed flow chamber dimensions.

Figures 5, 6 and 7 show the same plots as Figures 2, 3 and 4 however the Reynolds stress turbulence closure model is used instead of the k-ε closure scheme. The results do not change appreciably when a higher order turbulence closure scheme is used.

Figures 8, 9 and 10 show the effect of grid refinement. In these figures a 180 x 120 grid is used with the k-ε turbulence closure model. The results do not change appreciably (by comparison with Figures 2, 3, and 4) when the grid size is reduced. A small recirculation zone is predicted in the upstream corners of the chamber which was not seen in the coarser grid flow prediction (Figure 8); however, its velocity is less than 0.1 m/s (Figure 9).

In the next quarter, we will construct the jet flow facility and purchase all of the needed material (flowmeters, particles, etc.) in order to begin experimentation.

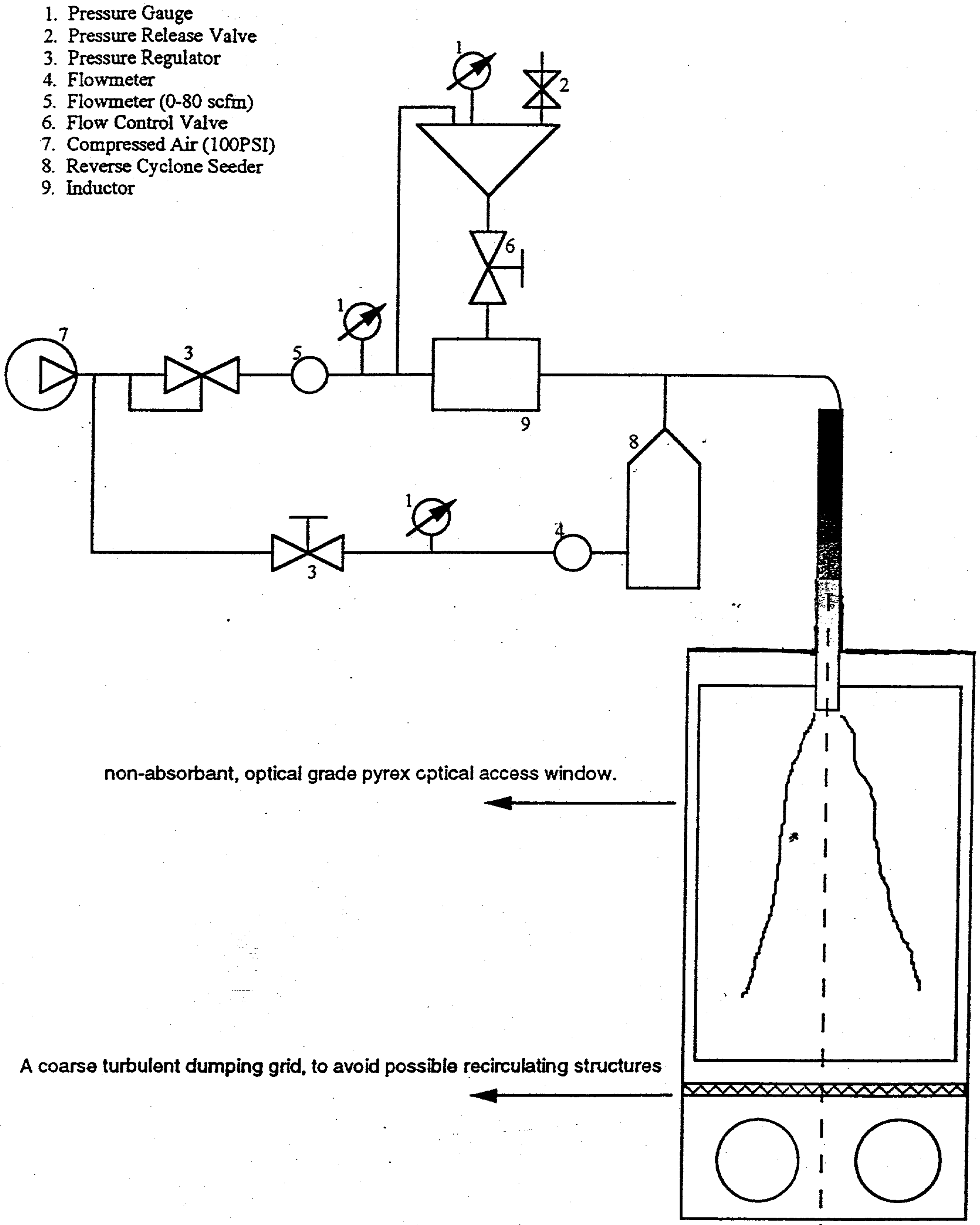
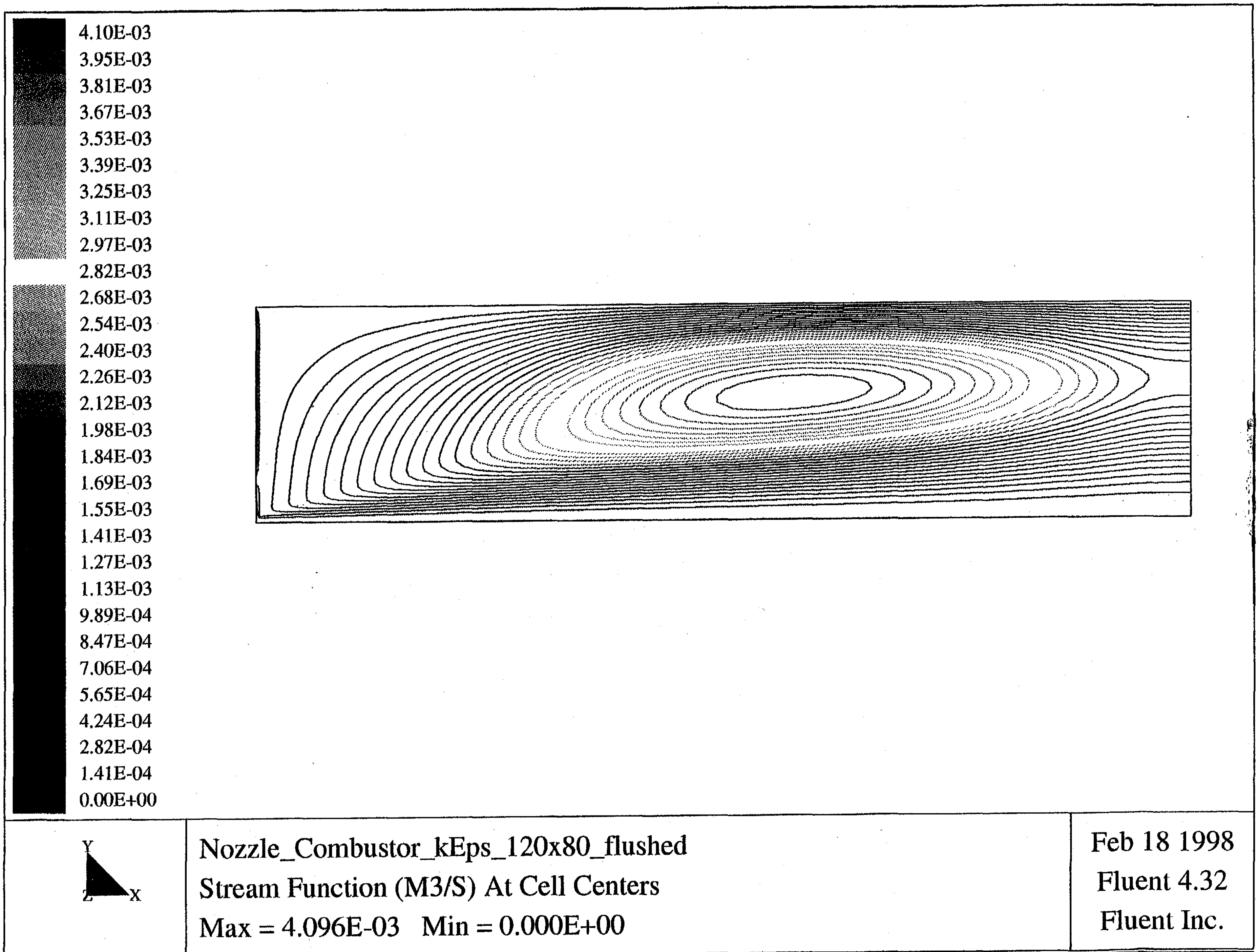

1. Pressure Gauge
2. Pressure Release Valve
3. Pressure Regulator
4. Flowmeter
5. Flowmeter (0-80 scfm)
6. Flow Control Valve
7. Compressed Air (100PSI)
8. Reverse Cyclone Seeder
9. Inductor
non-absorbant, optical grade pyrex optical access window.
A coarse turbulent dumping grid, to avoid possible recirculating structures

Figure 1



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Z
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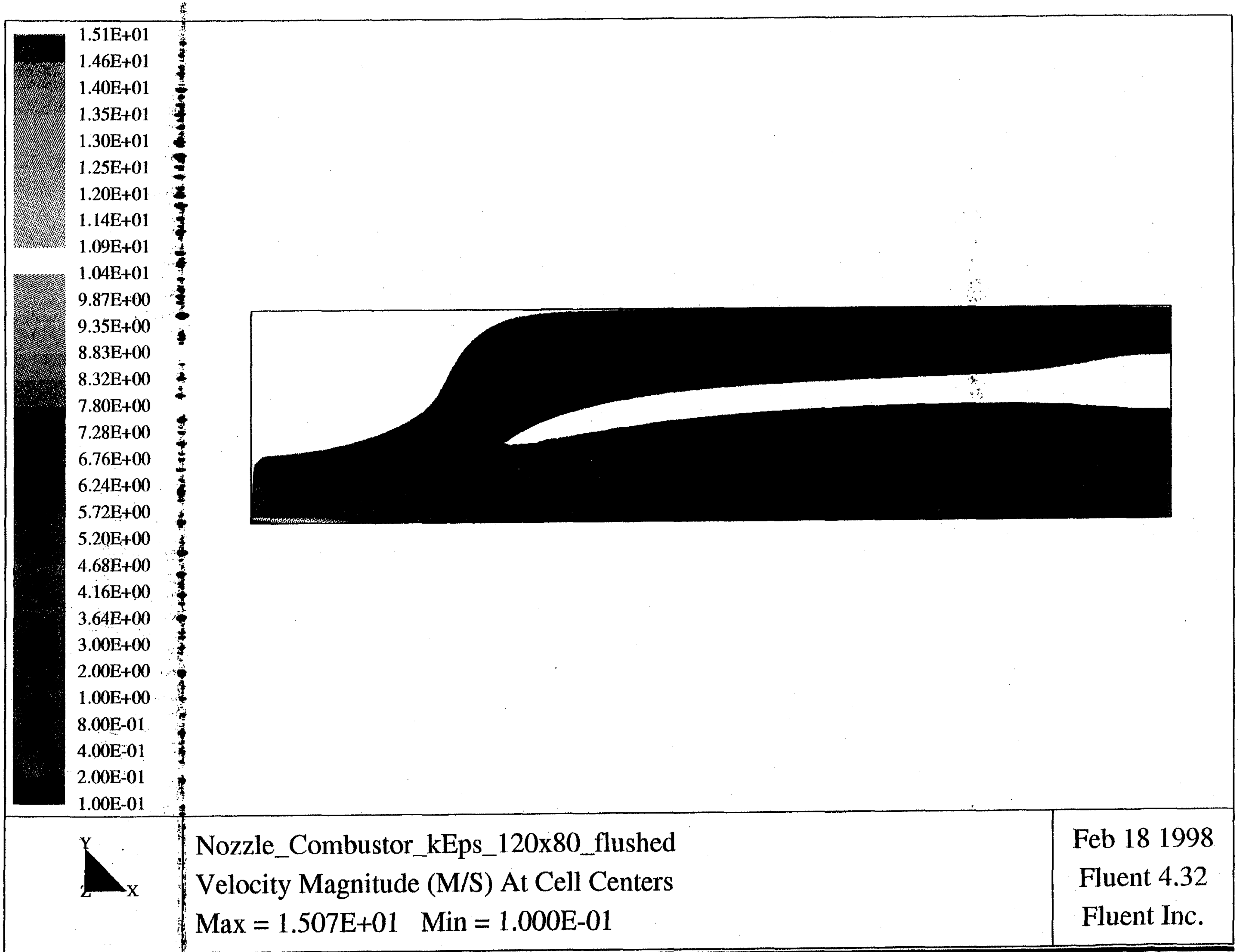
Feb 18 1998
Fluent 4.32
Fluent Inc.

Figure 2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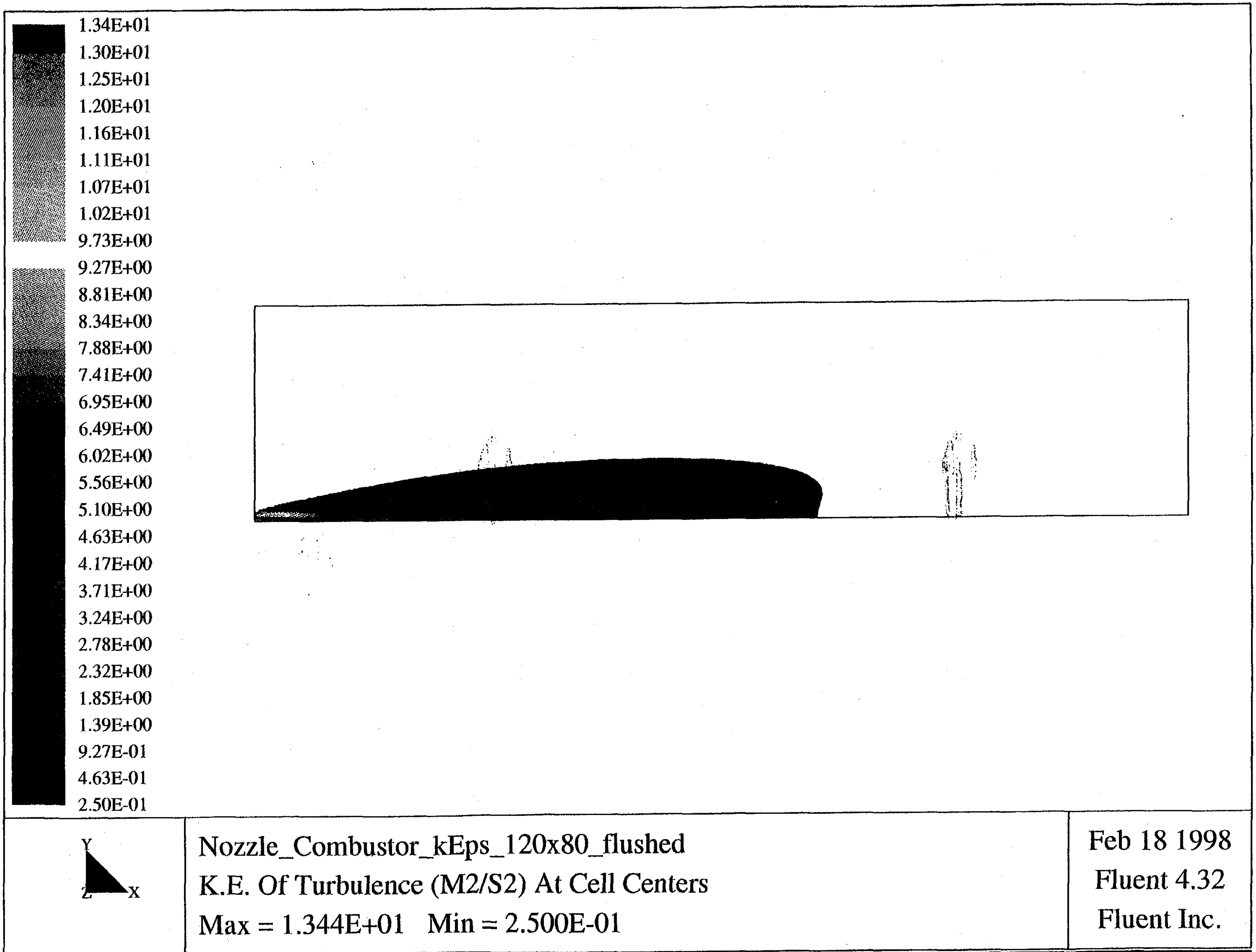
Fluent Inc.

Figure 3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9.27E+00
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8.34E+00
7.88E+00
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6.95E+00
6.49E+00
6.02E+00
5.56E+00
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4.63E+00
4.17E+00
3.71E+00
3.24E+00
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9.27E-01
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Y
X
Z
Nozzle_Combustor_kEps_120x80_flushed
K.E. Of Turbulence (M2/S2) At Cell Centers
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Feb 18 1998
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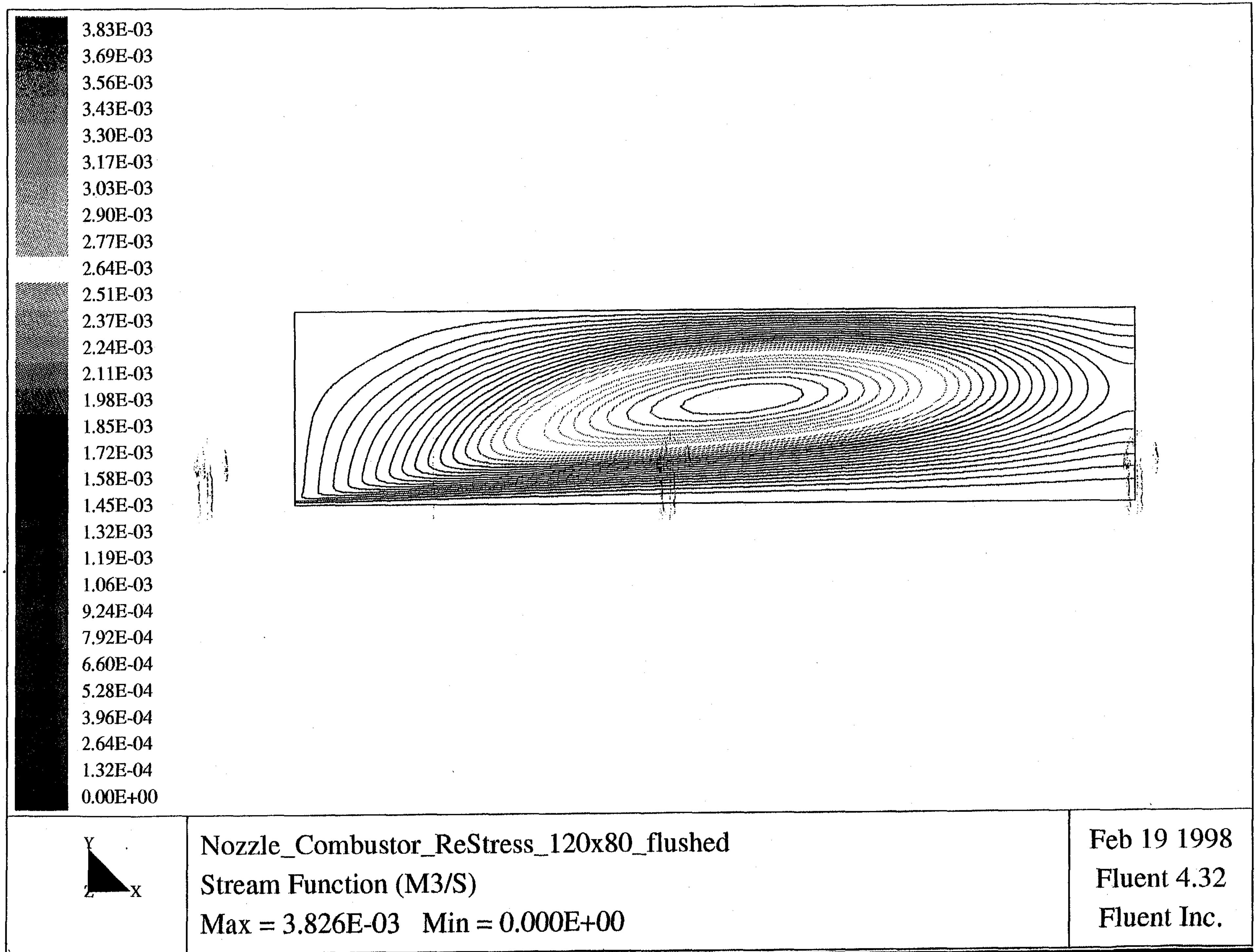
Fluent Inc.

Figure 4



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Y
Z
X
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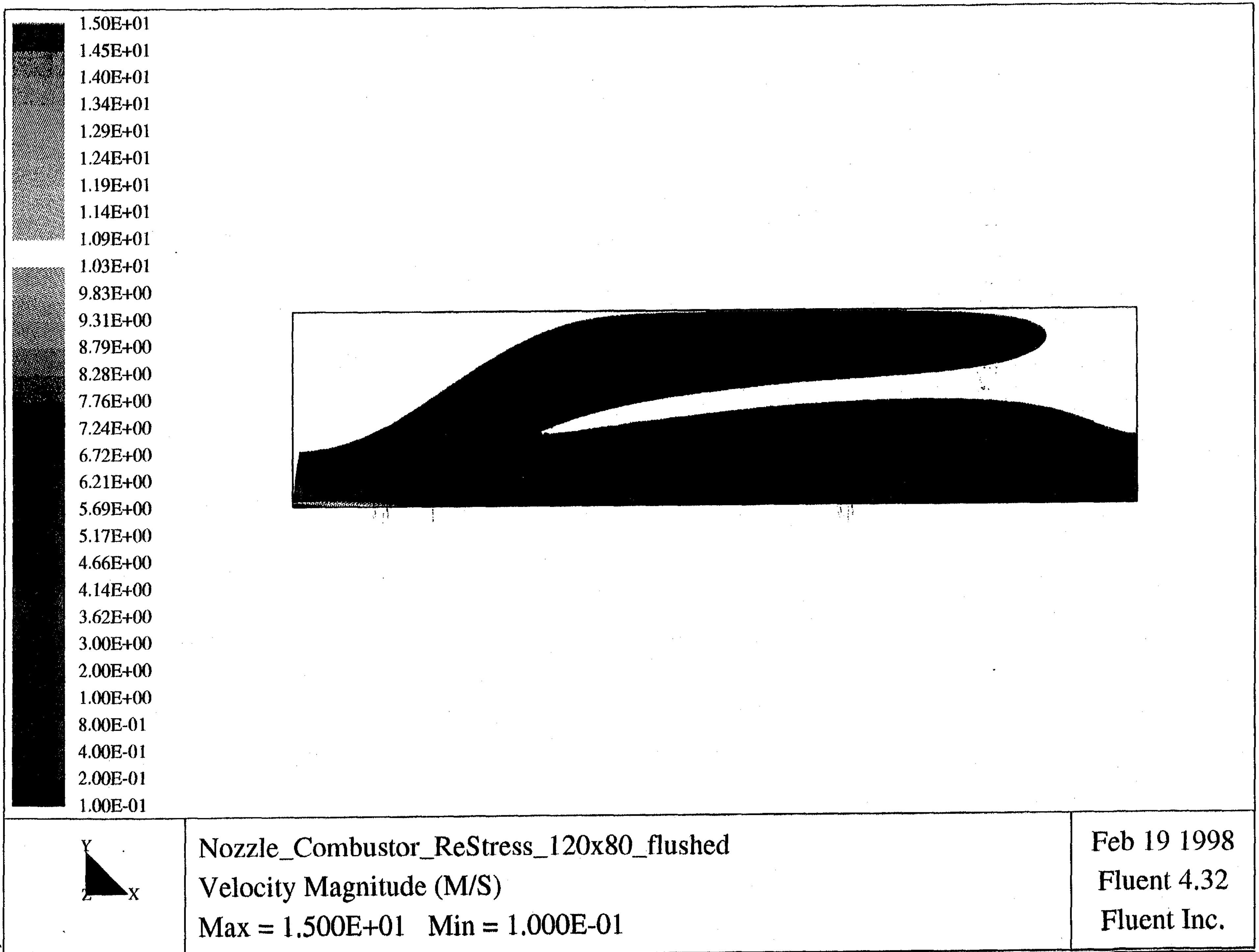
Fluent Inc.

Figure 5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7.24E+00
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5.17E+00
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3.00E+00
2.00E+00
1.00E+00
8.00E-01
4.00E-01
2.00E-01
1.00E-01
Y
Z
X
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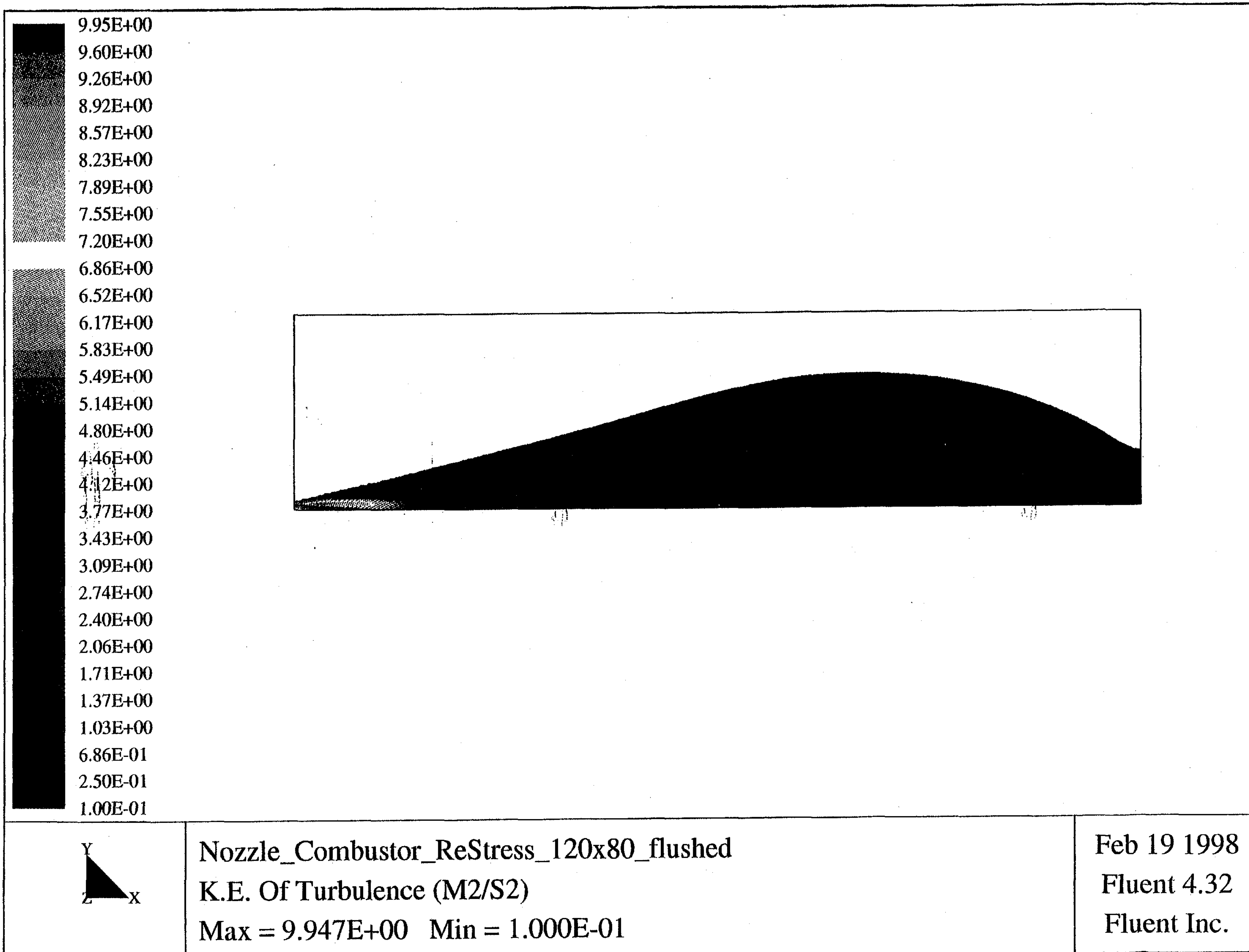
Fluent 4.32
Fluent Inc.

Figure 6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5.49E+00
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4.80E+00
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Y
Z
X
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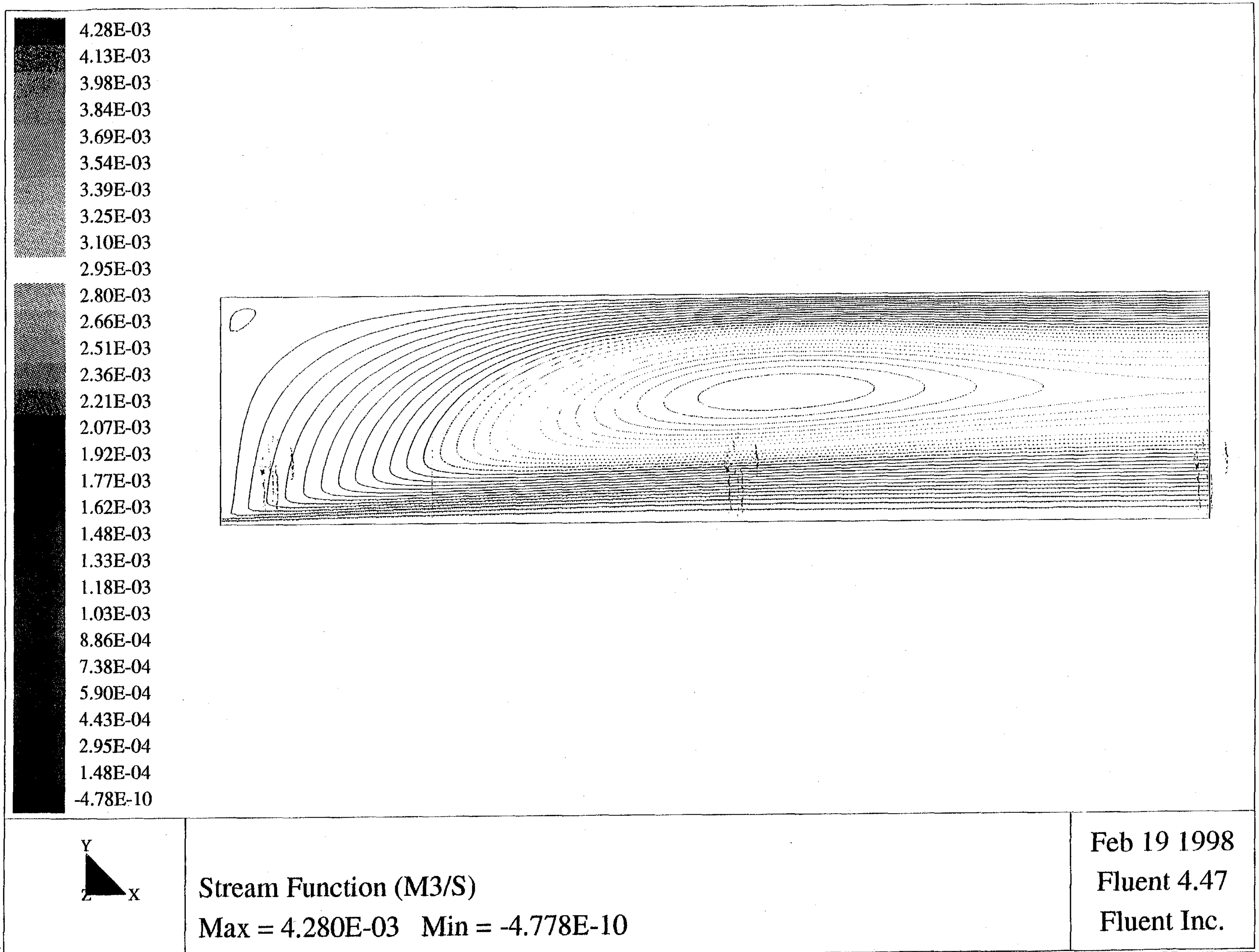
Figure 7



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Z
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Figure 8

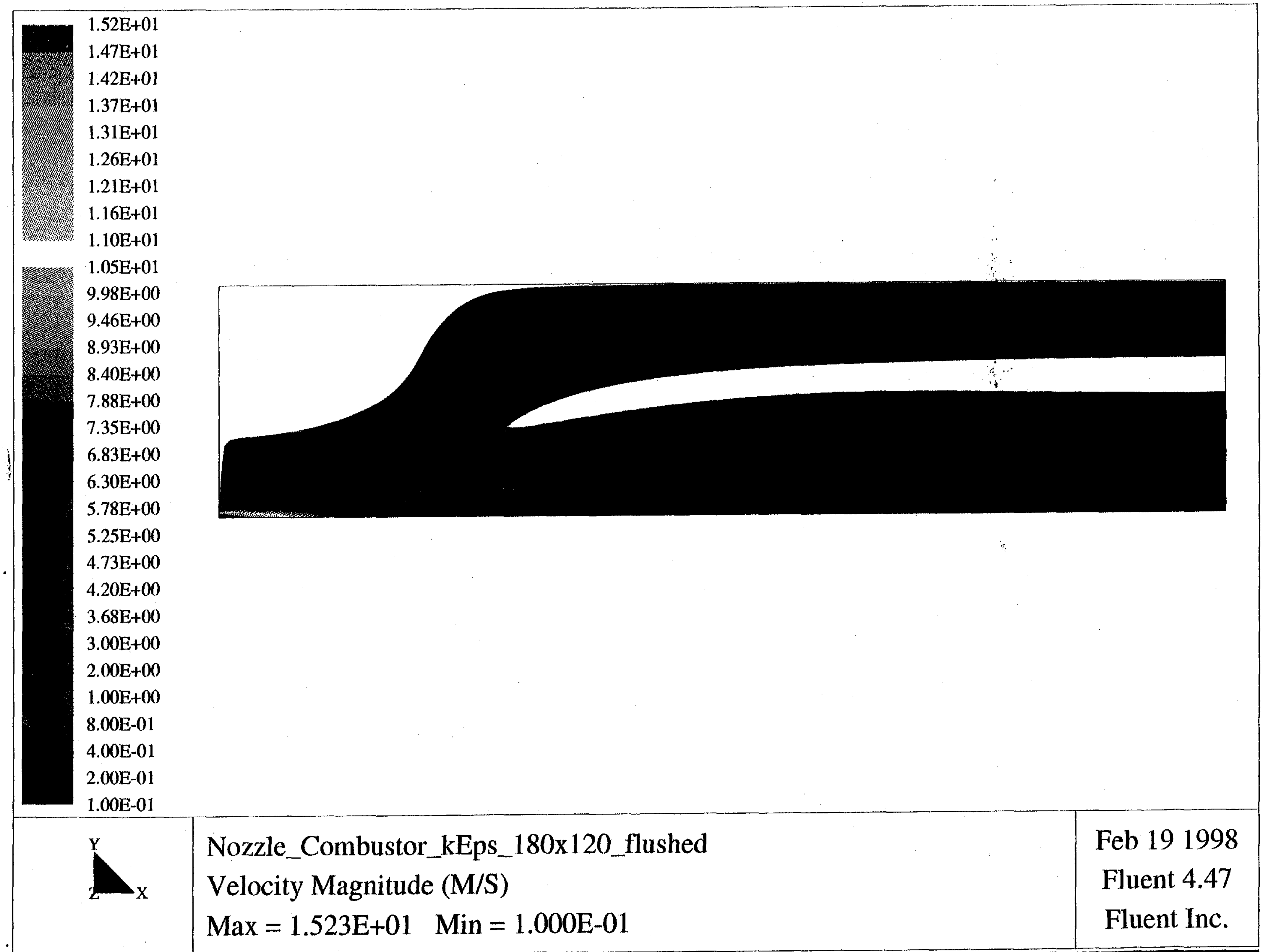
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Figure 9

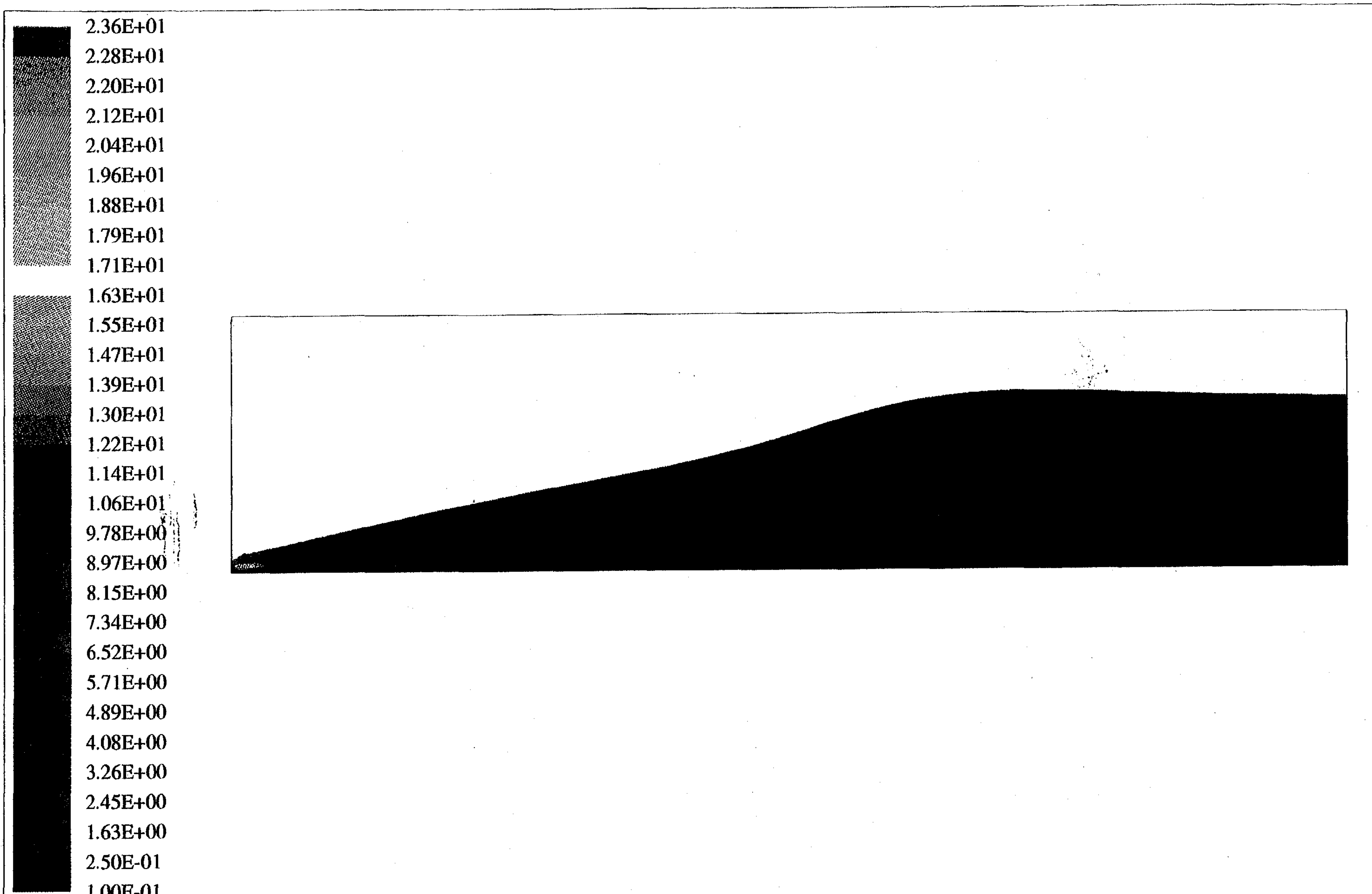

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Figure 10

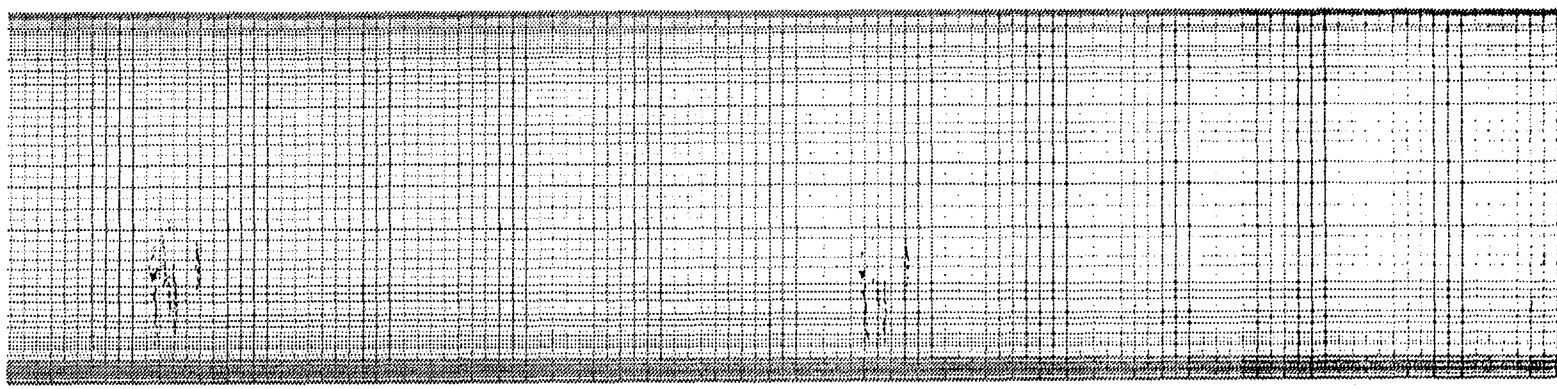

Figure 11

Grid (119 X 79)

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