Thermal analysis of various duct cross sections using altair hyperworks software

Article · November 2014

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Thermal analysis of various duct cross sections using altair hyperworks software

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Abstract

In this work thermal analysis and comparison of various duct cross sections is done computationally using Altair Hyperworks Software. Simple Analytical results were obtained for conduction and convection through the ducts which can be used to build up thermal circuit. The inner surface of all ducts is maintained at constant temperature and ambient air is at certain temperature that is less than inner surface temperature of pipe. Due to temperature difference heat will flow from higher temperature to lower temperature. Due to temperature difference heat will flow from higher temperature to lower temperature. The material of pipe provides conductive resistance and air provides convective resistance. Hence this is a mix mode of heat transfer. The heat transfer takes place in one dimension only and properties are considered to be isotropic. The ducts are assumed to be made of aluminium having known thermal conductivity and density. The surroundings of ducts have known convective heat transfer coefficient and temperature. The results are obtained on hyperview which are for heat flux, temperature gradient and grid temperature. The different characteristics can be obtained by varying the material of the ducts.

Keywords: Ducts, Altair Hyperworks

1. INTRODUCTION

A duct system installation is designed to ensure the thermal and acoustic comfort of a building's occupants, use energy efficiently and comply fully with safety requirements. Installation design takes into account the air exchange rates in the building, the number of its occupants and their activities, its interior characteristics and the materials from which it is constructed. Associated with pipelines, dump combustors; different ducting devices etc. are examples of the turbulent flow through change in cross section. To improve the performance of such applications, an accurate description of the flow patterns are required. The numerical analysis of the flow through an problem the experimental results are very rare because it is both difficult and costly to make detailed flow measurements under real operating conditions. So the numerical analysis becomes an extremely important and significant tool for the visualization and simulation of these types of problems. The flow in such devices is very complicated owing to generation of recirculation bubble and thereby changing the downstream flow structures. The sudden change in the surface geometry of the passage increases the pressure along the direction of flow. Due to this adverse pressure gradient the boundary layer separates at the sharp step edge. The resulting flow in the downstream thus behaves essentially like a free shear layer.

2. LITERATURE REVIEW

The convective heat transfer coefficient term is used to describe heat transfer from surface to a moving fluid. The flow may be forced using some external means or free caused by buoyancy forces arising from density difference. The flow may be laminar and turbulent which depends upon the Reynold's number. Heat transfer rate tends to be much higher in turbulent flow than in laminar flow. The rate of heat transfer by convection is usually function of surface area, geometry and thermo physical properties Mills and Ganesan, Second Edition (2009). In an external flow heat transfer is directly proportional to the temperature difference. When convective heat transfer coefficient is known than that can be finding by correlation given in hand book for external and internal flow. Knowing the value of h we can find the rate of heat transfer rate. Here, in the given case we know the

value of convective heat transfer coefficient. Laufer carried out in detail the first experiment on the fully developed turbulent flow in a circular duct. Chaurvedi first analyzed the flow characteristics in the axi-symmetric expansion. The effects of the sudden expansions and compressions on the turbulent boundary layer were presented by White. Vasilev et al numerically computed the turbulent flow in the sudden expansion of the channel. Szymocha presented the experimental analysis for the turbulent water flow in the downstream of a plane symmetric sudden expansion. Asymmetric contraction exists in case of flow diversion when the construction is needed in a part of the channel and the flow is running in the other part. The flow through the contracted section may be critical, sub critical or supercritical with sub critical flow upstream. In these studies, the effects of horizontal asymmetric channel contraction on the flow characteristics are presented and discussed based on experimental observations. He investigated the effect of asymmetric sudden and gradual contraction parameters on the flow when it changes from sub critical to supercritical through the contracted reach of the channel. G.Satish describes an analytical approach to describe the areas where Pipes (used for flow of fluids) are mostly susceptible to damage and tries to visualize the flow behavior in various geometric conditions of a pipe. The author suitably to discount macro scale hydrodynamics and fluid mechanics in favour of velocity slip conditions and free molecular flow analysis techniques. Then, an overview of macro scale fluid mechanics is given for pressure driven internal flow. These equations and derivations represent the foundational assumptions, theories, and flow behaviours of Newtonian fluids, and can be found in most introductory textbooks on the subject.

3. OBJECTIVE OF PRESENT WORK

Effort has been made to predict the heat flux and temperature gradient on the outer surface of the ducts under consideration. Subsequently, the type of duct can be selected as per the applications either heat transfer maximization or minimization.

4. MATHEMATICAL MODELING

4.1 Heat conduction through circular duct
Governing Equation
Assumptions

1. One dimensional steady state heat transfer.
2. Constant thermal conductivity of material.
3. No heat generation in the material.
4. The heat transfer coefficient between the duct and the surrounding fluid, i.e., air is constant.
5. Heat transfer by radiation is negligible.

Governing differential equation for the heat transfer through circular duct is as follows:

Figure 1 shows a circular duct cross section of inside radius r_1, outside radius r_2, length L, and thermal conductivity k. The inside and outside surfaces are maintained at constant temperatures Ts,1 and Ts,2, respectively with Ts,1 > Ts,2. Ambient temperature is T_∞=25°C
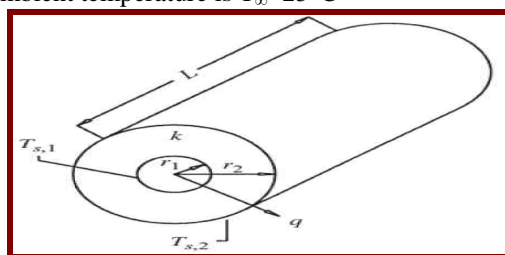

Fig.1 Heat transfer through a circular duct

For steady-state conduction in the radial direction with no internal heat generation and constant thermal conductivity, the general heat conduction equation is as follows:

$$\frac{d}{dr}\left(r\frac{dT}{dr}\right) = 0$$

Boundary Conditions
a) The temperature at the inner surface of the duct, i.e., at 20mm radius is 50° C.
Mathematically: T (r_1=20mm) = 50° C
(b) The ambient temperature is 25° C.
Mathematically: q_{cond}(r_2=25mm) = hdt

4.2 Thermal Resistance Concept
The thermal resistance can be expressed as electrical analogy given as:
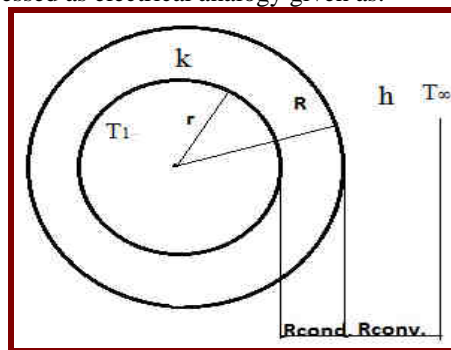

T1 ---------/\/\/\-------/\/\/\---------- T∞
Fig.2 Conductive and Convective resistance

Fig. 2 shows a circular duct cross section of inside radius r_1, outside radius r_2 and thermal conductivity k. The inside surface is maintained at constant temperatures T_1. Ambient temperature is T_∞=25°C. The convective heat transfer coefficient of surroundings is h.
The overall heat transfer is given by:

$$Q = \frac{\Delta Toverall}{\Sigma Rth}$$

Where Rth is total thermal resistance and is sum of conductive and convective resistance.
$$\Sigma Rth = Rcond + Rconv$$
Where,

$$Rcond = \frac{ln\,(R/r)}{2\pi kL}$$
$$Rconv = \frac{1}{2\pi RLh}$$

Rate of heat transfer is given by:

$$Q = \frac{2L(T_1 - T_2)}{\left(\frac{ln\,(R/r)}{k} + \frac{1}{hR}\right)}$$

5. PROBLEM FORMULATION

In the present work thermal analysis is done for the four types of ducts. Inner cross sections are same of all ducts. The circular duct is taken as reference. This implies the rectangular, square, elliptical have the same inner cross sections as that of circular. The material thickness is same in all types of ducts. The material thickness is to be taken 5 mm. The material of ducts is aluminium. In this case, the inner surface of the duct is constant 50ºCdue to flow of hot fluid. The ambient temperature is 25ºC. The direction heat flow will be from inner surface towards the surroundings. The material and the surroundings will provide the resistance to heat flow.The ducts considered for analysis are
   (a) Circular duct
   (b) Rectangular duct
   (c) Square duct
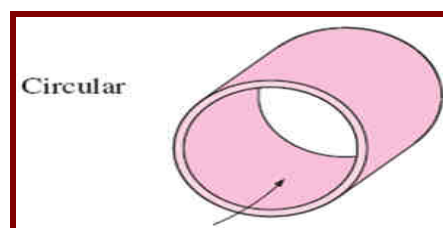   (d) Elliptical duct

Fig.3 Circular Duct

Dimensions:
(a) Circular duct
The dimensions of the circular duct are as follows:
The inner radius of the circular duct =20mm
Outer radius of the circular duct=25mm
Length of the circular duct=100mm
b) Rectangular duct
The dimensions of the rectangular duct are as follows:
-For the inner cross section
The length to width ratio =2:1
Length=50.142mm
Width=25.071mm
-For the outer cross section
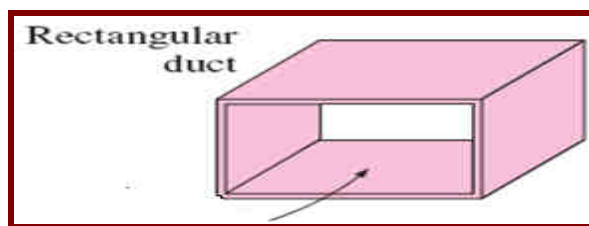Length=60.142mm
Width=35.071mm
Length=100mm

Fig.4 Rectanular Duct

(c) Square duct
The dimensions of the square duct are as follows:
For the inner cross section
The dimension =35.449mm
For the outer cross section
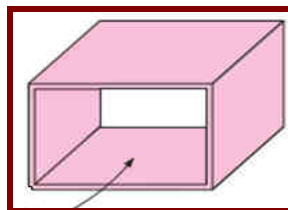The dimension=45.456mm
Length=100mm

Fig. 5 Square duct

(d) Elliptical duct
The dimensions of the elliptical duct are as follows:
The ratio of major to minor axis=2:1
For inner cross section
The dimension of the major axis=28.2842mm
The dimension of the minor axis=14.1421mm
For outer cross section
The dimension of the major axis=33.2842mm
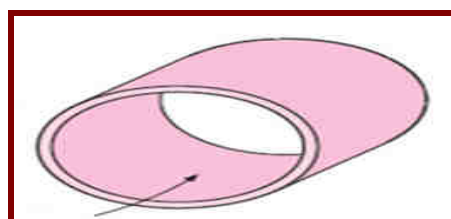The dimension of the minor axis=19.1421mm
The Length=100mm

Fig.6 Elliptical duct

Table-1 Properties used in analysis

1.	Material of joints	Aluminium
2.	Density(ρ)	2700kg/m^3
3.	Thermal conductivity(k)	237 W/m.K
4.	Coefficient of thermal expansion(α)	23.5×10^{-6}/K
5.	Poisson's Ratio(μ)	0.30
6.	Young's Modulus(E)	68.3 GPa
7.	Convective Heat Transfer Coefficient(h)	20 W/m^2.K

The modelling and meshing of the ducts according to the dimensions mentioned is done in HyperMesh. The thermal analysis is done in Radioss.

System of units used in RADIOSS

The unit system used for analysis in RADIOSS is millimetre-second-tonne (mm-s-t). In this system the length, time and mass are considered in millimetre, seconds and tonnes respectively. So, units of flux and temperature gradient in the results are as follows:

Flux: $\times 10^3$ W/m^2
Temperature Gradient: K/mm

6. ABOUT ALTAIR HYPERWORKS

Altair Hyper Works is the engineering frame work for product design for maximizing product performance, automating design process and improving profitability with an open and flexible environment. Built from the core up to be programmable, automated and interoperable with all major commercial CAD system and CAE solvers. Hyper works enable innovation by providing high end, value–based product design solution within one common engineering environment.

7. PROCEDURE

7.1 Modelling and Meshing In Hyper Mesh

The modelling of the ducts is done in Hyper Mesh as per the dimensions mentioned in previous section. The meshing of the models is also done in Hyper Mesh. The element density for all the joints is taken same, i.e., 40. Firstly, a 2D mesh is generated. Taking it as a reference the final 3D mesh is generated. It is also important to delete every other geometries and elements by masking the 3D mesh because they can create hurdles during the thermal analysis in radios. The final meshed joints are shown below:
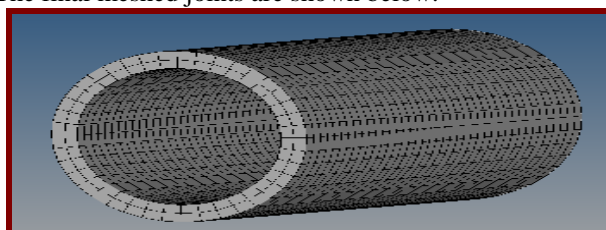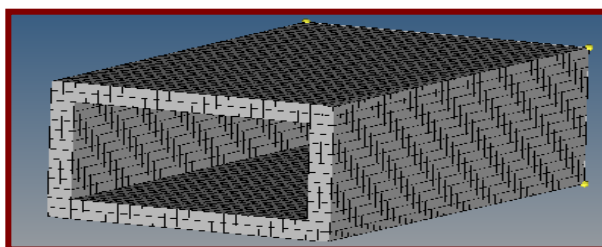

Fig.7 Meshing of circular duct
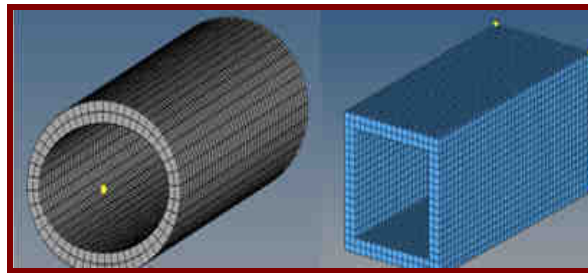

Fig.8 meshing of rectangular ducts

Fig.9 meshing of square and elliptical duct

7.2 Analysis in RADIOSS
Steps in given problem
• Create the thermal material and property
• Create and apply the thermal boundary conditions on the model
• Submit the job to RADIOSS
• Post-process the results in Hyper View

Step 1: Load the RADIOSS (Bulk Data) User Profile and draw the model.

Step 2: Create the thermal material properties. Create the material and property collectors before creating the component collectors.

Step 3: Link the material and property to the existing structure. Once the material and property are defined, they need to be linked to the structure.

Step 4: Create temperatures on the inner surface of the duct joint.

Step 5: Create ambient temperature.

Step 6: Create CHBDYE surface elements for heat convection. Surface elements are to be created to simulate the heat exchange between the solid pipe and the surrounding air.

Step 7: Define the convection boundary condition to surface elements

Step 8: Create a heat transfer load step. A RADIOSS steady state heat convection load step will be created which references the thermal boundary conditions in the load collector spc temp. The gradient, flux, and temperature output for the heat transfer analysis will also be requested in the load steps panel.

Step 9: Launch RADIOSS View and Post process the Results. Gradient temperatures and flux contour results for the steady state heat conduction analysis are computed from RADIOSS. Hyper View will be used to post process the results.
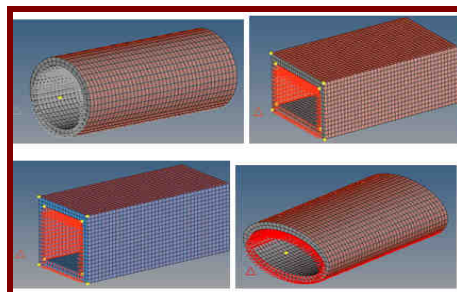

Fig. 10 The ducts after applying the loads and boundary conditions

Results are viewed in Hyper View.

8. RESULTS AND DISCUSSION
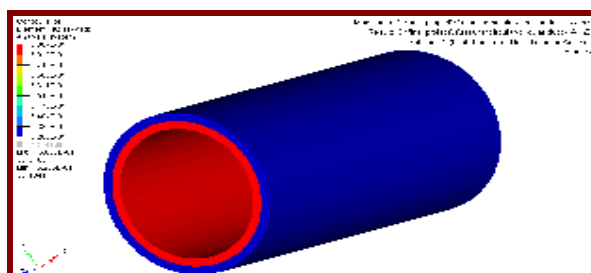### 8.1 Contour Plots Heat flux
(a) Circular Duct

Fig.11circular duct

The maximum heat flux on the outer surface of circular duct ranges from 0.5266 to 0.5335 units. Therefore the average maximum heat flux is 0.530 units, i.e., 530 W/m^2.
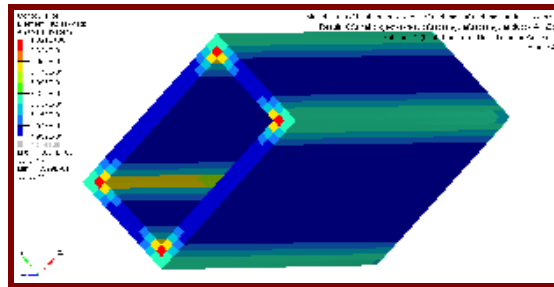
(b) Rectangular Duct

Fig.12 Rectangular duct

The maximum heat flux on the outer surface of rectangular duct ranges from 0.4999 to 0.5578 units. Therefore the average maximum heat flux is 0.529 units, i.e., 529 W/m^2

(c) Square Duct

Fig. 13 Square duct

The maximum heat flux on the outer surface of square duct ranges from 0.5009 to 0.5588 units. Therefore the average maximum heat flux is 0.5299 units, i.e., 529.9 W/m^2.
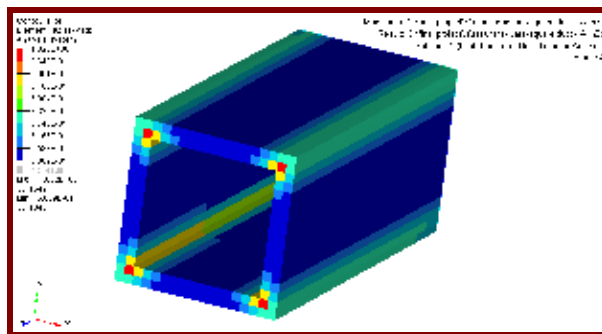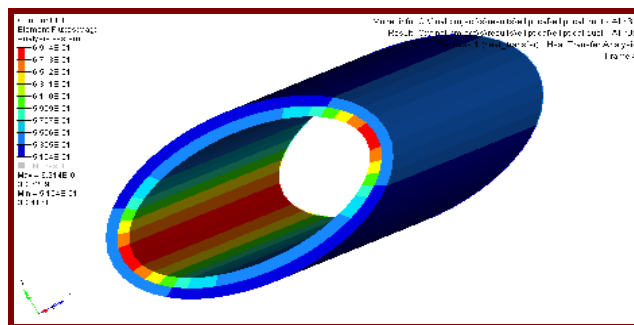
(d) Elliptical Duct

Fig.14 Elliptical duct

The maximum heat flux on the outer surface of elliptical duct ranges from 0.5104 to 0.5305 units. Therefore the average maximum heat flux is 0.5205 units, i.e., 520.5 W/m^2.

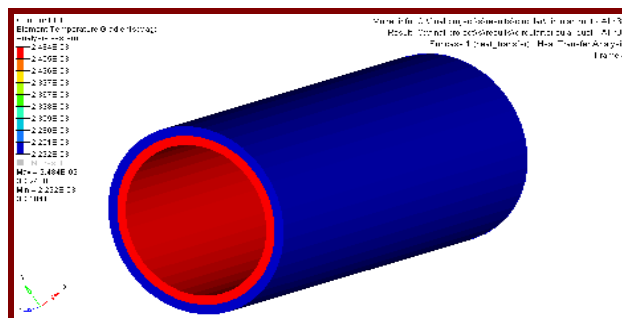**8.2 Contour Plots Temperature Gradient**

(a) Circular Duct

Fig.15 Temperature gradient-Circular duct

The maximum temperature gradient on the outer surface of circular duct ranges from 0.002222 to 0.002251 K/mm. Therefore the average maximum temperature gradient is 0.002237 K/mm.

(b) Rectangular Duct

Fig.16 Tempareture gradient-Circular Duct

The maximum temperature gradient on the outer surface of rectangular duct ranges from 0.002109 to 0.002354 K/mm. Therefore the average maximum temperature gradient is 0.002232 K/mm.

(c) Square Duct

Fig.17 Square duct

The maximum temperature gradient on the outer surface of square duct ranges from 0.002114 to 0.002358 K/mm. Therefore the average maximum temperature gradient is 0.002236 K/mm.

(d)Elliptical Duct

Fig.18 Elliptical duct

The maximum temperature gradient on the outer surface of elliptical duct ranges from 0.002154 to 0.002238 K/mm. Therefore the average maximum temperature gradient is 0.002196 K/mm.

8.3 Graphs

(a) Circular Duct

(b)Rectangular Duct

(c)Square Duct

(d) Elliptical Duct

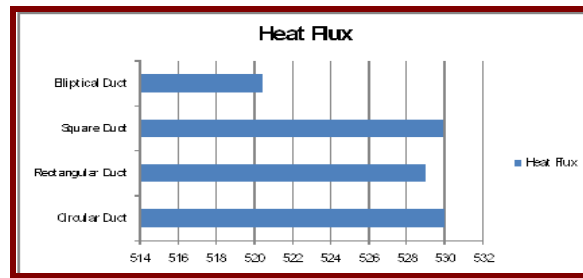**Graph.1 Max. Flux (avg.) in outer surface**
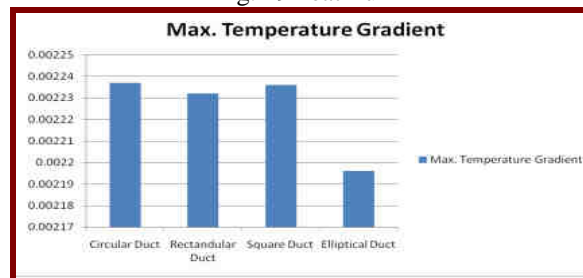
Fig. 19 heat flux

Fig.20 max temperature gradient

9. CONCLUSION

The maximum heat flux on the outer surface is available in the circular duct. Thus, it can be used in applications where maximization of heat transfer is desired. The minimum heat flux on the outer surface is available in the elliptical duct. Thus, it can be used in applications where minimization of heat transfer is desired.

REFRENCES

1. Y. A. Cengel (2010) "Heat and Mass Transfer – A Practical Approach. 3rd ed." Tata McGraw Hill.
2. Mahesh M. Rathore (2010) "Engineering Heat and Mass Transfer. 2nd ed." University Science Press.
3. ISOVER, HVAC Ducts Handbook. 2012.
4. Spiral Manufacturing Co., Inc. (2013) "A Complete Line of High Pressure Ductwork", Volume 5.
5. Y. A. Cengel and M. A. Boles (2010) "Thermodynamics – Engineering Approach. 6th ed.", Tata McGraw Hill.
6. Brekovsky , B.M. Polyvikov, V.K., (1987) "Numerical study of problem on high intensive free convection"
7. Jian Su, (2001) "Improved lumped models for asymmetric cooling of a long slab by heat convection", Int. Comm. Heat Mass Transfer, Vol. 28, pp.973-983.
8. Fried, E (1970) "Thermal conduction contribution to heat transfer at contacts" pp. 24-33.
9. Keshavarz P. & Taheri M. (2007), "An improved lumped analysis for transient heat conduction by using the polynomial approximation method", Heat Mass Transfer, Vol. 43, pp.1151–1156.
10. Teixeira M.G, Rincon b M.A. and I.- S. Liu, (2009), "Numerical analysis of quenching – Heat conduction in metallic materials", Applied Mathematical Modelling, vol.33, pp.2464–2473
11. Wheeler R.F, (1984),"Thermal conduction of fuel element material"
12. Giedt W.H,(1972)"Investigation of variation of point unit heat transfer coefficient around a cylinder normal to air stream" McGraw-Hill, New York
13. Kays W.M and Crawford, (2005) "Convective heat and mass transfer" 4th edition McGraw-Hill Higher Education
14. Yovanovich M.M, (1964) "Recent Developments in Thermal contact Gap and joint conduction theories and experiment"
15. P. Bhatt and A. Gupta, (2012) "Thermal Analysis Of Hollow Pipe Using Altair Hyperworks", International Journal of Engineering Research & Technology, ISSN: 2278-0181, Vol. 1 Issue 6,
16. Frank P. Incropera and David P. Dewitt (2009) "Fundamentals of Heat and Mass Transfer", Wiley Publication, Fifth Edition.

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