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N95- 27360

TRANSITIONAL FLOW IN THIN TUBES FOR SPACE STATION FREEDOM RADIATOR

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SUMMARY

A two dimensional finite volume method is used to predict the film coefficients in the transitional flow region (laminar to turbulent) for the radiator panel tubes. The code used to perform this analysis is CAST (Computer Aided Simulation of Turbulent Flows). The information gathered from this code is then used to augment a Sinda85 model that predicts overall performance of the radiator. A final comparison is drawn between the results generated with a Sinda85 model using the Sinda85 provided transition region heat transfer correlations and the Sinda85 model using the CAST generated data.

INTRODUCTION

Plans for the radiator for Space Station Freedom were to have several panels connected by fluid manifolds. The manifolds on either side of the radiator are connected by 12 thin tubes (1/8", 3.175 mm) per panel. (see Fig. I). Flow through the tubes is not a constant rate. It varies as a function of the position of the station as it relates to the sun. The flow in the thin radiator tubes can go from a low flow rate (laminar) to a high flow rate (turbulent). Accurate prediction of the radiator's thermal performance depends on several aspects, including the ability to predict the film coefficients of the fluid in the panel tubes. A grey area in this prediction is in the area of transition flow ($2300 < Re < 10,000$), especially in thin tubes. Small changes in the film coefficient can effect predictions of the radiator performance and freezing of the working fluid.

SYSTEM DESCRIPTION

A radiator panel tube has an inner diameter of 1/8", and the tube is 12' long (3.175 mm, 3.658 m). This translates to an L/D of 1150. The Sinda85 model (see Ref. I) took the entire tube into account, along with the thermal connections to the heat sink (the space environment). This allowed the model to predict the tube's fluid exit temperature.

The CAST model (see Ref. II) only modeled the tube to an L/D of 70. This allowed the flow to become fully developed and predict accurate film coefficients. A compiled table of these coefficients was then input into a second Sinda85 model. This model is an exact duplicate of the above mentioned Sinda85 model except for the differing film coefficients.

THE CAST CODE

It is assumed that the reader is familiar with the basic structure of Sinda85. No discussion will be held on the development of that model. The cast model does need some discussion. CAST is a two dimensional, finite volume fluid analysis code. After generating a grid that used an L/D of 70, the model was run for three known scenarios. The first was a laminar ($Re = 2300$) case. The predicted film coefficients were within 5% of the classic $Nu = 3.66$ correlation (see Table I and Ref. III).

Next, the geometry was changed by increasing the diameter by a factor of 10. The flow was increased to obtain a Reynold's Number of 10,000. Here, the predicted value of the film coefficient was

Table I: Laminar and Turbulent Control Cases

Re	UA (Ref III)	UA (CAST)
2300	11.9 [btu/hr/°F]	11.4
10,000 (10D)	4.25	3.57
10,000	24.0	23.5

within 10% of the classic Dittus/Boelter correlation (Nu = 0.023 * Re^.8 * Pr ^.3, see Ref. III).

Finally, the diameter of the tube was brought down to the actual value (0.125") and the model was run again at a Reynold's Number of 10,000. This time the model prediction was within 3% of the Dittus/Boelter correlation. These three results give a good deal of confidence to the ability of CAST to accuratly predict the transition flow film coefficients.

The CAST code input was now modified to run in the transition region. One point of interest was to determine that if acceleration and deceleration of the flow would effect the onset of turbulence (see Ref. IV). When the acceleration parameter K (defined beow) reached a value of 2.0e-06, laminarization becomes significant and and the heat transfer capabilities of the fluid are altered. In the case of the radiator flows, the change in the velocity rates was not great enough to have any impact. (K < 1.0e-09) In other words, the flow accelerated and decelerated at slow enough rates so as not to effect the heat transfer.

$K = \upsilon \ (dU/dx) / U^2$

where υ = kinematic viscosity

U = stream velocity

Another area of concern was the effect of the transient conditions would have upon the system. Sinda85 uses an implicit (backward) differencing scheme to handle its transient fluid calculations. An ideal fluid analysis code will have a long term history of each fluid element, as this may have an effect on the performance of the fluid. The CAST model was run in steady state form for a series of Reynold's numbers (see table II). A set of transient runs spanning the same range as the steady state runs was also completed. The end result being, once again, the flow rates changed slowly enough that steady state runs were accurate enough to be used to predict the transient cases. This allowed the film coefficients obtained for the transient CAST runs to be implemented in the Sinda85 model with confidence.

Table II: Reynold's Number vs. CAST Film Coefficient Calculations

Re	UA
3000	15.2 [btu/hr/°F]
4000	20.8
5000	21.4
6000	21.5
7000	23.3
8000	23.4
9000	23.5
10000	23.6

RESULTS

Figure II shows the results of the CAST model over the range 3000 < Re < 10,000. Film coefficients versus L/D and Re are presented. Film coefficients were sampled over the length of the tube for each flow rate. The film coefficients were calculated in the following manner:

$$\Delta T = (\oint Ti\ Ui) / Uave - Tw$$

$$q = (T1 - Tw)\ k / \Delta y$$

$$htc = q / \Delta T$$

Where
Ti = Incremental Axial Temperature
Ui = Incremental Axial Velocity
Uave = Mean velocity
Tw = Wall (boundary) temperature
q = Heat flux
T1 = Temperature of increment next to the wall
k = Thermal Conductivity
htc = Film Coefficient

Table III shows the fully developed film coefficients obtained from CAST versus the Sinda85 film coefficients for the range of Reynold's numbers. Sinda85 uses two correlations over the area of concern, Over the range 1960 < Re 6420, Sinda85 uses Hausen's correlation:

$$Nu = 0.116\ (Re^{.667} - 125)\ Pr^{.3}$$

And over the range Re > 6420, Sinda85 used the Dittus/Boelter equation.

Table III was generated using the mean values for each flow rate of the film coefficients from an L/D of 50 out to an L/D of 70.

Table IV is a the final table that lists the radiator panel tube exit temperatures generated by the two Sinda85 models.

Table III: Sinda85 and CAST Film Coefficients

Re	UA (Sinda85)	UA (CAST)
3000	6.0 [btu/hr/°F]	15.2
4000	9.5	20.8
5000	12.5	21.5
6000	15.5	21.5
7000	18.0	23.3
8000	20.0	23.4
9000	22.0	23.5
10000	24.0	23.6

Table IV: Sinda85 and CAST Radiator Tube Exit Temperatures

Re	Temp (Sinda85)	Temp (CAST)
3000	-35.8 [°F]	-36.8
4000	-28.9	-29.5
5000	-29.2	-24.5
6000	-20.8	-20.9
7000	-18.2	-18.3
8000	-16.2	-16.3
9000	-14.6	-14.6
10000	-13.3	-13.2

CONCLUSIONS

A review of Table III shows that higher film coefficients are obtained using the CAST code instead of Hausen's correlation (which is empirically derived at low Reynold's numbers). The reason for the increased heat transfer can be explained by the effect of the thin tubes. Turbulent mixing boundary layers take up a larger percentage of the axial flow. This leads to more fluid mixing and enhances heat transfer.

The higher film coefficients lead to lower fluid exit temperatures, ie, the radiator becomes more effective. However, the film coefficients are only one part of the thermal network of the radiator. The overall effect is small and well within any margin of uncertainty so as not to change any conclusions of the radiator performance made by the original Sinda85 model.

A side note to the conclusions must be considered here. Had the radiator tubes been much shorter, the entry region effects would have been much greater. Figure II shows the increased UA's for at the inlet conditions and as the flow starts to develope. It is clear that there is enhanced heat transfer in this area. The overall length of the radiator panel tubes makes this insignificant but for shorter tubes, this augmented heat transfer would have had to have been considered.

RECOMENDATIONS

The particular version of the CAST code used is refered to as a High Reynold's Number (HRN) version. It is best suited for flows well above the laminar region and into turbulent. For the lower Reynold's number cases (the ones close to $Re = 2300$) the Low Reynold's Number (LRN) version, also known as the k-ε model could be used. The LRN could be used to verify, or modify, the HRN values.

REFERENCES

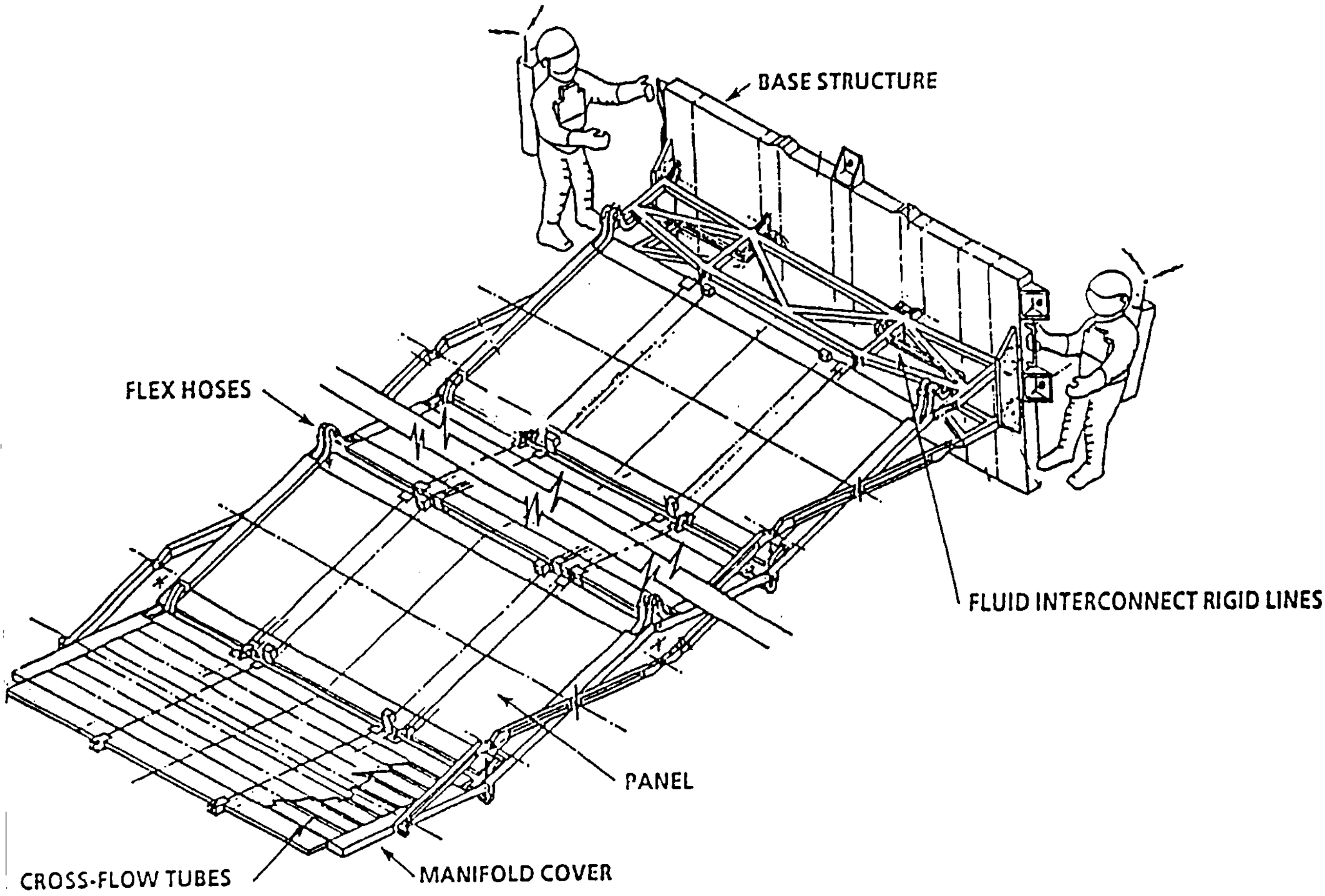
I: Sinda85 User's Manual, V2.3, Cullimore, Goble, Jensen, & Ring, 1992

II: CAST User's Manual, Peric & Scheuerer, 1989

III: Fundamentals of Heat Transfer, Incropera & De Witt,1981

IV: On the Prediction of Laminarization, Laudner & Jones, 1969

Figure I: RADIATOR



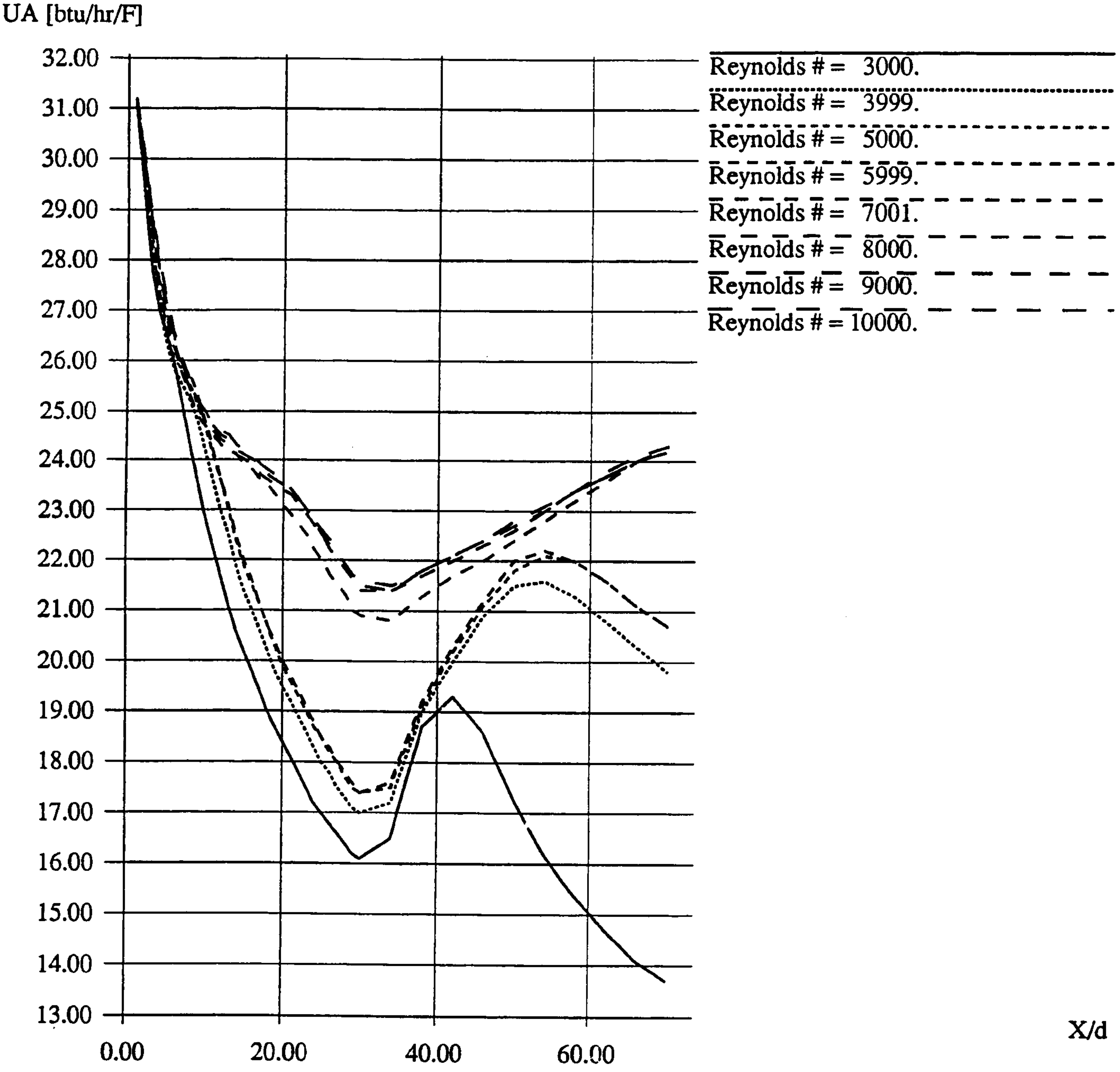


Figure II: Transition UA's vs Re and X/d