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# Experimental Investigation of Heat Transfer Enhancement in Radiating Pin Fin

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**Abstract**

A literature review shows that much of work on radiating fins has been carried out analytically and numerically. Presently, a radiating pin fin with grooves and threads on its outside surface is investigated experimentally. A test facility with a vacuum chamber and instrumentation is fabricated. The heat input to the fin is varied such that the base temperature is maintained constant under steady state. Based on a study of effect of vacuum, using available resources, the chamber is designed for a vacuum of 80 mm Hg such that the contribution of convection to the total heat transfer could be ignored. The study shows that there exist optimum angle of grooves and number of threads per inch for which the heat loss per unit mass is a maximum. The grooved / threaded radiating fin loses 1.4 and 1.2 times greater heat per unit mass, respectively, compared to the bare pin fin.



*Keywords:* Radiating fin; Cavity effect; Threaded fin; Effect of Vacuum; Optimization;

## 1. Introduction

Since radiation is the only possible mode of heat transfer in space, radiating fins are used in spacecraft for waste heat rejection. The radiating fin or a space radiator is generally optimized with respect to mass, since mass is at a premium on spacecraft.

A review of literature shows that various researchers have attempted to improve the design and provide the mass optimized space radiators. Wilkins [1] studied the problem of designing a thin fin which transfers a given rate of heat from a base at a temperature and which has the smallest mass. Sunil Kumar and Venkateshan [2] optimized tubular radiator with annular fins on a non-isothermal base. The presence of an optimum fin outer diameter for a given pipe diameter has been brought out. A set of useful correlations which will enable the designer to quickly evaluate the performance of the system is developed for different profiles. Krishnaprakas [3] presented mass optimized design of a straight rectangular plate fin array extending from a plane wall. Ramesh and Venkatesan [4] used a two dimensional finite difference method of analysis to observe the thermal performance characteristics of a tubular space radiator with attached fins. A wide range of thermal and geometrical parameters is considered for the analysis and a new dimensionless heat dissipation parameter has been defined for the designer's usage. Krikkis and Razelos [5] presented the correlations for optimum dimensions of longitudinal rectangular and triangular radiating fins with mutual irradiation. Chung, B. T. F.; Nguyen, L. D.,[6] analyzed various radiating spines to determine the general relationships for spine dimensions, the heat transfer characteristics and a least material profile under the optimum condition. Razani, A.; Zohoor, H. [7] studied a conducting-radiating spine with an arbitrary profile to find the optimum dimensions of the spine. Schnurr, N. M.; Townsend, M. A.; Shapiro, A. B. [8] optimized the radiating fin arrays with respect to weight. A non linear optimization approach was used to determine the minimum weight design for radiating fin arrays used in space applications. Black and Schoenhals [9], and Black [10] studied the directional radiation properties of specially prepared V groove cavities and also optimized the directional emission from V groove and rectangular cavities. Gorchakov and Panevin [11] & [12] obtained a numerical solution of the system of equations describing the thermal state of the fin. Schnurr, N. M [13] optimized the design of longitudinal and triangular radiating fins with respect to weight. Dhar, P. L.; Arora, C. P. [14] developed a method of carrying out the minimum weight design of finned surfaces of various types. Tanaka, S.; Kunitomo, T. [15] analyzed numerically the radioactive and convective heat transfer from longitudinal and rectangular fin array in

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a plane surface by applying the Monte Carlo method. Optimization of the heat transfer performance of the finned plate system has been examined for various combinations of parameters. Karam, R. D.; Eby, R. J. [16] presented temperature optimized design of a rectangular fin under constant heat flux condition. Venkateshan, S. P.; Gopinath, Ashok,[17] studied the problem of a uniform area radiating fin for large values of the radiation conduction interaction parameter and developed for improving the previously known asymptotic solution to make it applicable for relatively smaller values of radiation conduction interaction parameter. Razani, A, Zohoor, H. [18] presented suitable methods for parametric studies and design analysis of optimum spines. Zaulichnyi, E. G [19] analyzed the problem of heat transfer by means of radiators with finned heat pipes with one-dimensional approximation and proposed an algorithm to design radiators of a specified capacity with constraints on their weight and dimension.

Love, T. J., Francis, J. E. [20] analyzed longitudinal radiating fins equally spaced around a cylindrical heat source. Eslinger, R. G.; Chung, B. T. F. [21] presented a finite element solution for the heat transfer from a radiating and convecting fin or fin arrays. Karam, R. D [22] presented a method, which optimizes the selection of linearization parameters to obtain a best approximate solution to radiation problems. Truong, H. V.; Mancuso, R. J[23] presented One-dimensional steady-state solutions for radiation from front and rear surfaces of an annular fin having different front and rear emissivities. Chang, H. V [24] developed a computer model of a heat pipe radiator based on two correlations for the rectangular radiating fin efficiency. Chung, B. T. F, Nguyen, L. G [25] presented a systematic study on optimum dimensions and the associated heat transfer characteristics for radiating longitudinal fins. Badari Narayana, K, Uma Kumari, S, Narayana Murthy, H. [26] presented an analysis to optimize both mass and area of radiating fin based on the design calculations with uniform heat flux applied to the fin. Torikoshi, K, Kawazoe, M, Fujiwara, M, Kurosaki, Y[27] studied theoretically and experimentally the Heat transfer augmentation due to surface radiation in an annulus with fins. Nguyen, H. T.; Lehtinen, A. M [28] analyzed numerically Conduction and radiation heat transfer between two stationary arrays of interleaving gray fins of rectangular profile are parametrically analyzed for a wide range of fin emissivity, dimensionless fin base temperatures, and pertinent dimensionless ratios relating the fin dimensions and fin material properties. Lee, Ron C. [29] presented an analytical treatment of radiation fin effects in cryogen systems. Bhise et al. [30] investigated a corrugated fin structure for space radiator applications and presented correlations for the optimum corrugation angle and maximum heat loss to space. Srinivasan and Katte [31] proposed a grooved radiator with higher heat loss per unit mass compared to the flat radiator. Deiveegan and Katte [32] Proposed a hollow conical radiating fin, which radiates 5 times greater heat per unit mass than the corresponding solid pin fin, and showed that an optimum angle, thickness and emissivity exist for mass optimized performance.

The review of literature shows that much of work on space radiators has been carried out analytically and numerically. There have been a very few attempts to experimentally study the effect of modification of geometry of a radiating pin fin on its heat transfer characteristics. Presently, a radiating pin fin with threads and grooves on its outside surface are investigated experimentally. A test facility with a vacuum chamber and instrumentation is fabricated. The heat input to the fin is varied such that the base temperature is maintained constant under steady state. The study shows that there exist optimum angle of grooves and number of threads per inch for which the heat loss per unit mass is a maximum.

## 2. Experimental Setup and Procedure

A test facility, as shown in Fig. 1, consisting of a vacuum chamber, control panel and instrumentation for measuring the vacuum, temperature and heat supplied is fabricated. The low cost vacuum chamber of size 0.3 × 0.45 m is constructed using 4 mm thick GI sheet. One of the walls is made detachable such that the radiating fin to be tested could be changed easily. The radiating fin to be tested is fitted to this detachable wall. Four passages at the top and one passage at the bottom of the chamber are provided. Three passages at the top are used for the electrical and thermocouple connections. These three passages are sealed with epoxy resin compound, which is used to mold the broken underground electric cables. Fourth passage at the top is fitted with a valve for controlling the vacuum in the chamber. The passage at the bottom is used for sucking air from the chamber, using the suction line of an air compressor. A reciprocating compressor of capacity 10 kg/cm$^2$ is used to for this purpose. The interior surfaces of chamber as well as the radiating fin are painted with black-board paint.

A vacuum gauge is provided to measure the vacuum inside the chamber. The control panel consists of an ammeter, voltmeter, temperature indicator and a dimmer-stat to vary the input power supply to the heater. A heating element, operating through the dimmer-stat, is connected to one end of the pin fin. Ten K-type thermocouples are connected along the length of fin at equidistance. The vacuum chamber is designed for a maximum vacuum of 80 mm Hg such that the contribution of convective heat transfer to the total heat transfer could be ignored. This value is chosen based on a study of effect of vacuum on the total heat transfer by the fin.

The pin fin chosen in the present study is made of aluminum, with a length of 150 mm and a diameter of 19.05 mm. All experiments are carried out under steady state, for a root temperature of 40$^o$C. The power input to the heater is controlled such that, the root of fin is maintained constant at the desired temperature, after attaining steady state, which is observed by the variation of temperatures with time.

## 3. Geometries of the Fin Used in the Experiment

The geometry, which is proposed in the present work, is shown in the Fig. : 2, 3, and 4. Threads and grooves are provided for the radiator surface, instead of the conventional flat surface.

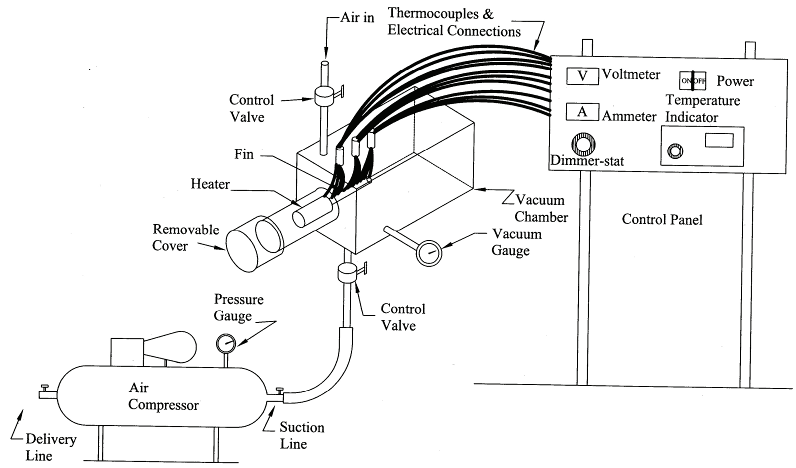

Fig. 1: schematic of experimental set up

Conduction of heat takes place along x direction. This geometry has applications in solar panels and fin-tube radiators. The proposed space radiator is supposed to be placed in between the bank of tubes carrying coolant.

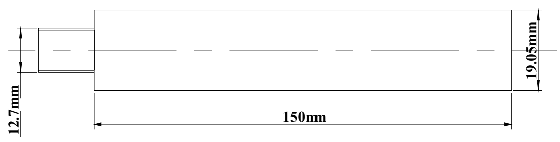

Fig.2: pin fin

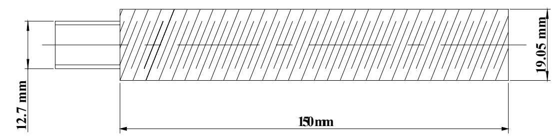

Fig.3: pin fin with threads

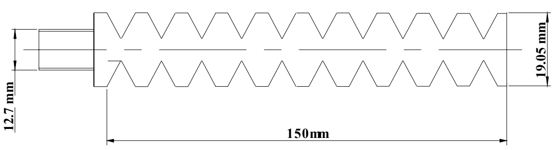

Fig.4: Pin Fin With “V” Grooves

## 4. Experimental Uncertainty

The current input, voltage, total heat supplied to the heater and surface temperature of the fin are four major parameters in this study. The uncertainty analysis for the derived quantities was carried out following the procedure given in the book Experimental methods for Engineers by Holman. The uncertainty of the Voltage measurement was estimated to be maximum 16.1%. The uncertainty in the measurement of current was found to be 2.33% max. The uncertainty in heat flow measurement was 16.1 %. The percentage of error associated with temperature measurement is 1% up to 70°C.

## 5. Results and Discussion

### *5.1. Effect of Vacuum on Heat Loss*

The effect of vacuum on the total heat loss by the fin is studied first, in order to minimize the effect of convective heat transfer from the fin. Fig. 5 shows the effect of variation of absolute pressure on the total heat loss by the fin, which includes the effects of convective as well as radioactive losses. The vacuum in the chamber is controlled by adjusting the air flow into the chamber using the valve. For an absolute pressure of 0.2133 bars, the total heat loss is 4.4 W, which is 43.14 % of the total heat loss corresponding to the atmospheric pressure. For an absolute pressure of 0.1066 bars, the total heat loss is 3.78 W, which is 37.06 % of the total heat loss corresponding to the atmospheric pressure. For these two values of absolute pressures, the difference in the contributions of radiation to the total heat transfer is only about 6 %. Hence an absolute pressure of 0.1066 bar (80 mm Hg) is chosen as the chamber pressure for subsequent experiments.

### *5.2. Effect of Angle of “V” Threads*

Heat transfer characteristics are studied for a radiating fin with “V” threads on its outside surface, having a depth of 1.3 mm. The effect of angle of threads on heat loss and heat loss per unit mass is shown in Fig. 6. For a given depth of threads, the surface area available for radiation decreases as the thread angle increases. However, the heat loss by radiation not only depends on the surface area, but also on the cavity effect. Hence, with increase in the thread angle, the heat loss and heat loss per unit mass vary non-monotonically. An optimum angle of threads for which the heat loss and heat loss per unit mass are high

For the chosen fin, the optimum thread angle is about $40^{o}$, and the threaded fin loses about 1.4 time's greater heat per unit mass than the corresponding pin fin. With further increase in the thread angle, the effect of decrease of surface area is dominant, and hence the heat loss does not vary significantly.

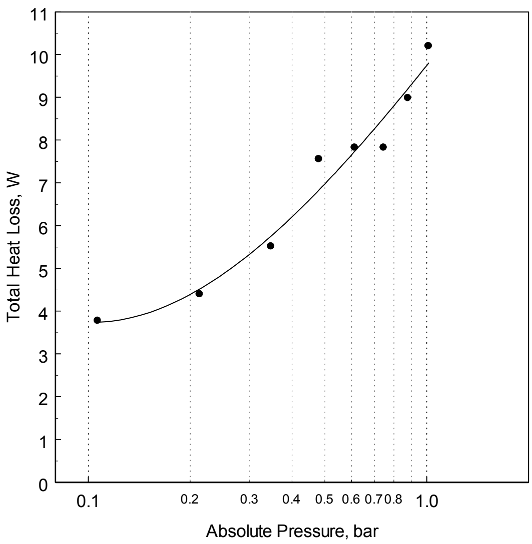


Fig. 5: effect of variation of vacuum on heat transfer

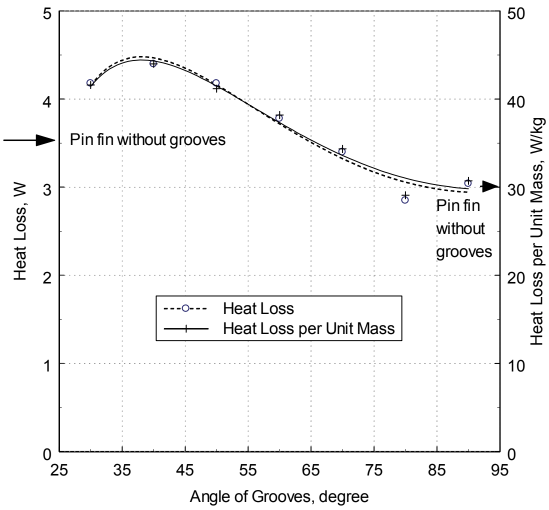


Fig. 6: effect of angle of grooves on heat transfer

When the thread angle is decreased from $90^o$ to $40^o$, the heat loss or heat loss per unit mass increases by about 1.5 times, which is significant. Further, the provision of threads is beneficial if the angle of threads is less than $60^o$, because, if the thread angle is greater, the heat loss for the threaded fin would be less than the corresponding pin fin without threads. However, from heat loss per unit mass point of view, the threaded fin would be beneficial if the thread angle is less than $75^o$.

### *5.3. Effect of Threads Per Inch on Heat Loss*

Finally, the heat transfer characteristics are studied for a radiating fin with standard metric "V" threads on its outside surface. The effect of number of threads per inch on heat loss and heat loss per unit mass is shown in Fig. 7. For a given number of threads per inch, there will be a corresponding depth of threads. Hence, as the number of threads per inch varies, the surface area available for radiation, the cross sectional area available for conduction of heat and the cavity effect would vary. Hence, with increase in the number of threads per inch, the heat loss and heat loss per unit mass vary non-monotonically.

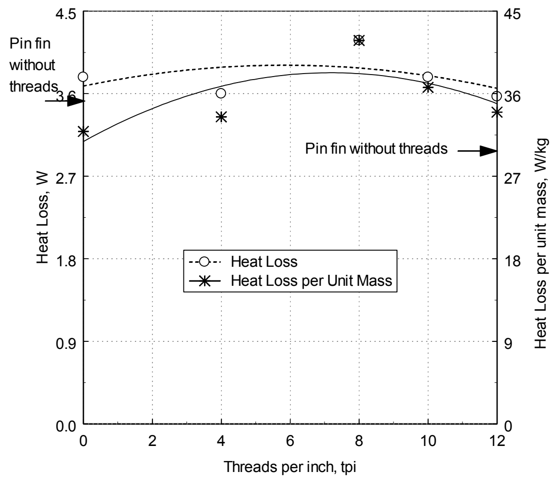


Fig. 7: effect of thread per inch

There exists an optimum number of threads per inch for which the heat loss or heat loss per unit mass are maximum. For the chosen fin, as seen from Fig. 7, the optimum number of threads per inch lies between 6 and 8. There exists a range of number of threads per inch for which the heat loss and heat loss per unit mass for the threaded fin are greater than those for the corresponding unthreaded pin fin. For the chosen fin, for the optimum number of threads per inch of eight, the threaded fin loses about 1.2 time's greater heat per unit mass than the corresponding pin fin. The heat loss per unit mass varies significantly with the number of threads per inch compared to the heat loss.

## 6. Conclusion

The effect of modification of surface geometry for a radiating pin fin has been investigated experimentally. A test facility consisting of a vacuum chamber, control panel and instrumentation for measuring the temperature, vacuum and heat supplied is fabricated. The vacuum chamber is designed for a maximum vacuum of 80 mm Hg such that the contribution of convective heat transfer to the total heat transfer could be ignored. For a given base temperature, the effect of vacuum, angle of grooves and number of threads per inch are studied. The study shows that there exist optimum angle of grooves and number of threads per inch for which the heat loss per unit mass is a maximum. Corresponding to the optimum groove angle and number of threads per inch, the grooved / threaded fin loses 1.2 to 1.4 time's greater heat per unit mass compared to the radiating pin fin.

## References


[1] Wilkins J.E., Jr., "Minimizing the Mass of Thin Radiating Fins", J. Aerospace Science, Vol. 27, 1960, 145-146.

[2] S. Sunil Kumar and S.P.Venkateshan, "Optimized Tubular Radiator with Annular Fins on a Non-Isothermal Base, Int. J. Heat and Fluid Flow", Vol.15, 399-409, 1994.

[3] Krishnaprakas C. K., "Optimum Design of Radiating Rectangular Plate Fin Array Extending From a Plane Wall", J. Heat Transfer, Vol. 118, 490-493, 1996.

[4] Ramesh N. and S. P. Venkateshan, "Optimum Finned Tubular Space Radiator", Heat Transfer Engineering, Vol. 18, 69-87, 1997.

[5] Krikkis R.N. and Panagiotis Razelos, "Optimum Design of Spacecraft Radiators with Longitudinal Rectangular and Triangular Fins", J. Heat Transfer, Vol.124, 805-811, 2002.

[6] Chung, B. T. F.; Nguyen, L. D., "Thermal analysis and optimum design for radiating spine of various geometries, Heat transfer science and technology"; Proceedings of the International Symposium, Beijing, People's Republic of China, Oct. 15-18, 1985 (A87-33101 13-34). Washington, DC, Hemisphere Publishing Corp., 510-517, 1987.

[7] Razani, A.; Zohoor, H. , "The optimum dimensions of radioactive spines", Proceedings of Space 90, the Second International Conférence, Albuquerque, NM, Apr. 22-26, 1990. Vol. 2 (A91-27576 10-12). New York, American Society of Civil Engineers, p. 1316-1325, 1990.

[8] Schnurr, N. M.; Townsend, M. A.; Shapiro, A. B., "Optimization of radiating fin arrays with respect to weight", ASME, Transactions, Series C - Journal of Heat Transfer, Vol. 98, 1976, 643-648.

[9] Black W.Z. and Schoenhals R.J., "A Study of Directional Radiation Properties Specially Prepared 'V'-Groove Cavities", J. Heat Transfer, Vol. 90, 1968, 420-428.

[10] Black W.Z., "Optimization of the Directional Emission from V-Groove and Rectangular Cavities", J. Heat Transfer, Vol. 95, 1973, 31-36.

[11] Gorchakov V.S., and Panevin I.G., Effectiveness of Radiating Fins Covered with V shaped Grooves, http://techreports.iarc.nasa.gov/egi-in/NTRS, 1975.

[12] Gorchakov V.S., and Panevin I.G, "Efficiency of Radiating Fins Covered with V shaped Grooves", J.High temperature, Vol.13,No.4, 1976, 733-738.

[13] Schnurr, N. M., "Radiation from an array of longitudinal fins of triangular profile", AIAA Journal, Vol. 13, 1975, 691-693.

[14] Dhar, P. L.; Arora, C. P. "Optimum design of finned surfaces", Franklin Institute, Journal, Category: Fluid Mechanics and Heat Transfer, Vol. 301, 1976, 379-392.

[15] Tanaka, S.; Kunitomo, T., "Numerical analysis of radioactive-convective heat transfer from an extended surface by the Monte Carlo method," JSME, Bulletin, Vol. 21, 1978, 258-265.

[16] Karam, R. D.; Eby, R. J., "Linearized solution of conducting-radiating fins," AIAA Journal (Fluid Mechanics and Heat Transfer), Vol. 16, 1978, 536-538.

[17] Venkateshan, S. P.; Gopinath, Ashok, "Asymptotic analysis of a uniform area radiating fin" , Canadian Society for Mechanical Engineering, Transactions, Vol. 11, No. 2, 1978, 103-108.

[18] Razani, A, Zohoor, H. "Optimum dimensions of convective-radioactive spines using a temperature correlated profile", Franklin Institute, Journal (ISSN 0016-0032) Category: Fluid Mechanics and Heat Transfer, Vol. 328, No. 4,1991, 471-486.

[19] Zaulichnyi, E. G. "Possibilities for improving the characteristics of a radiator cooler through the use of finned heat pipes as radiating elements", Sibirskii Fiziko-Tekhnicheskii Zhurnal (ISSN 0869-1339) , Category: Fluid Mechanics and Heat Transfer, 1991, 20-26.

[20] Love, T. J.; Francis, J. E. "A linearized analysis for longitudinal fins with radioactive and convective exchange" Thermo physics and Heat Transfer Conference, Palo Alto, Calif., AIAA, 1978.

[21] Eslinger, R. G.; Chung, B. T. F. "Periodic heat transfer in radiating and convecting fins or fin arrays", American Institute of Aeronautics and Astronautics and American Society of Mechanical Engineers, Thermo physics and Heat Transfer Conference, Palo Alto, Calif., AIAA ,1978.

[22] Karam, R. D "Optimum solution of linearized radiation equations," Proceedings of the First International Conference , Swansea, Wales, 1979.

[23] Truong, H. V.; Mancuso, R. J. "Performance predictions of radiating annular fins of various profile shapes", American Society of Mechanical Engineers and American Institute of Chemical Engineers, Joint National Heat Transfer Conference, Orlando, Fla., ASME 5, 1980.

[24] Chang, H. V "Optimization of a heat pipe radiator design," Thermo physics Conference, Snowmass, CO, 1984.

[25] Chung, B. T. F, Nguyen, L. G. "Optimization of design parameters for radiating longitudinal fins of various geometries", AIAA, Aerospace Sciences Meeting, Reno, NV, 1986.

[26] Badari Narayana, K, Uma Kumari, S, Narayana Murthy, H., "Analysis of circular tapering radiator plates", Proceedings of the Eighth International Heat Transfer Conference, San Francisco, CA, Volume 2 (A87-30676 12-34). Washington, DC,1986.

[27] Torikoshi, K, Kawazoe, M, Fujiwara, M, Kurosaki, Y, "Heat transfer augmentation due to surface radioactive exchange effect of internal fins in an annulus, Proceedings of the Twenty-fourth National Heat Transfer Conference and Exhibition, Pittsburgh, PA, 1987

[28] Nguyen, H. T.; Lehtinen, A. M, "Radiation and conduction between interleaving fins - Numerical and linearized solutions," AIAA, Aerospace Sciences Meeting, Reno, NV, 1988.

[29] Lee, Ron C., "Radiation fin effects in cryogen systems," AIAA, Thermo Physics Conference, Buffalo, NY, 1989.

[30] Navin V. Bhise, Subrahmanya S. Katte and Venkateshan, S. P., A Numerical Study of Corrugated Structure For Space Radiators, 16th National and 5th ISHMT-ASME Heat and Mass Transfer Conference, Kolkotta, 2002.

[31] Srinivasan, K., and Subrahmanya S.Katte, Analysis of Grooved Space Radiator, 17th National and 6th ISHMT-ASME Heat and Mass Transfer Conference, Kalpakkam, India, 2004.

[32] M. Deiveegan and Subrahmanya S. Katte, "One Dimensional Analysis of Hollow Conical Radiating Fin", J. Thermo Physics and Heat Transfer, Vol. 18, 2004, 277-279.