



LESZEK KONIECZNY, D.Sc., N.A.
Ship Design and Research Centre
Gdańsk

MSC NASTRAN application to prediction of heat leakage through fish hold wall section

SUMMARY

The paper presents results of the heat transfer analysis, performed with the use of MSC NASTRAN, of 14 m hold wall section of a fishing vessel. The results are compared with available experimental results as well as other computations.

Some differences revealed from the comparison and their possible sources are left to further considerations.

INTRODUCTION

The heat flow analysis presented in the paper is a pilot calculation for a further, much bigger, purpose project on thermal analysis of a large 650 000 cu ft reefer vessel. The project is supported by State Committee for Scientific Research. The main subject of the project is thermal stress determination with the effect of insulation accounted for. Temperature pattern in a refrigerated hold steel structure is the first step of solution.

Three factors significantly affect heat flow through the hold boundaries. The first is insulation thickness which varies significantly in practice. The second is penetration of steel frames which act as „thermal bridges” across the insulated section, dramatically increasing heat flow in some cases. The third factor relates to materials and fasteners for the inside liners. Sheet steel, plywood and fibreglass are common as inside liners of the hold.

Heat transfer through hold wall section was investigated in the paper [1] to improve prediction of heat leakage through fish hold boundaries of steel fishing vessels. A finite difference heat transfer model was developed and eight fish hold wall sections representative of a 14 m boat were tested by using the „guarded hot box” technique. A good agreement was obtained between the predicted and test results. Both are used as the base for verification of the research results reported in the paper.

The research was aimed at better understanding of the factors influencing thermal resistance of hold sections and better appreciation of the potential hazards of poor insulation practice. The specific task is to develop a finite element model capable of predicting the thermal resistance of hold wall sections.

METHOD OF SOLUTION

The prediction model is based upon the steady state, two dimensional heat conduction equation :

$$\frac{\partial}{\partial x} \left[k(x, y) \frac{\partial T}{\partial x} \right] + \frac{\partial}{\partial y} \left[k(x, y) \frac{\partial T}{\partial y} \right] = 0 \quad (1)$$

with convective boundary conditions on the cold and warm surfaces :

$$-k(x, y) \frac{\partial T}{\partial y} = h(T_s - T_a) \quad (2)$$

and with adiabatic boundary conditions on the other two surfaces :

$$\frac{\partial T}{\partial x} = 0 \quad (3)$$

The problem was solved by using MSC NASTRAN Thermal Analysis Solver 153 for a finite element mesh described further, according to the User's Guide [2]. When the temperature distribution was calculated, heat flux, average cold and warm surface temperatures, thermal transmittance, panel conductance, and panel resistance were computed.

The calculations were performed for Structure 2 (Fig. 1) used in the experimental verification described in [1]. The finite element mesh is shown in Fig. 2 for only one flat bar frame, assuming that no heat flow occurs between frames, acc. to (3). The mesh is equivalent to the finite difference method mesh acc. to [1], provided that each QUAD4 element is centered in an appropriate finite difference method node location.

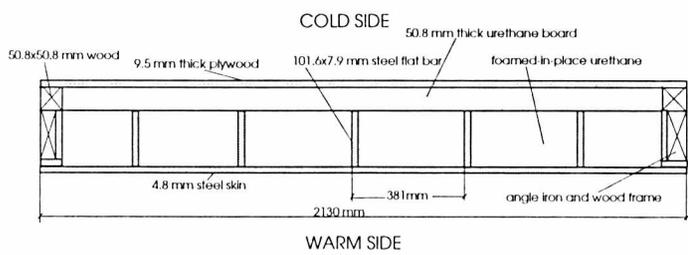


Fig.1. Structure 2 (1.78 m wide) with flat bar frames, according to [1]

894	847	850	853	899	921	924	927	930	933	936	939	942	945	948	951	954	957	960	963	966	969	972	975	978	981	984	987	990	993	996	999	1002	1005	1008	1011	1014	1017	1020	1023	1026	1029	1032	1035	1038	1041	1044	1047	1050	1053	1056	1059	1062	1065	1068	1071	1074	1077	1080	1083	1086	1089	1092	1095	1098	1101	1104	1107	1110	1113	1116	1119	1122	1125	1128	1131	1134	1137	1140	1143	1146	1149	1152	1155	1158	1161	1164	1167	1170	1173	1176	1179	1182	1185	1188	1191	1194	1197	1200	1203	1206	1209	1212	1215	1218	1221	1224	1227	1230	1233	1236	1239	1242	1245	1248	1251	1254	1257	1260	1263	1266	1269	1272	1275	1278	1281	1284	1287	1290	1293	1296	1299	1302	1305	1308	1311	1314	1317	1320	1323	1326	1329	1332	1335	1338	1341	1344	1347	1350	1353	1356	1359	1362	1365	1368	1371	1374	1377	1380	1383	1386	1389	1392	1395	1398	1401	1404	1407	1410	1413	1416	1419	1422	1425	1428	1431	1434	1437	1440	1443	1446	1449	1452	1455	1458	1461	1464	1467	1470	1473	1476	1479	1482	1485	1488	1491	1494	1497	1500	1503	1506	1509	1512	1515	1518	1521	1524	1527	1530	1533	1536	1539	1542	1545	1548	1551	1554	1557	1560	1563	1566	1569	1572	1575	1578	1581	1584	1587	1590	1593	1596	1599	1602	1605	1608	1611	1614	1617	1620	1623	1626	1629	1632	1635	1638	1641	1644	1647	1650	1653	1656	1659	1662	1665	1668	1671	1674	1677	1680	1683	1686	1689	1692	1695	1698	1701	1704	1707	1710	1713	1716	1719	1722	1725	1728	1731	1734	1737	1740	1743	1746	1749	1752	1755	1758	1761	1764	1767	1770	1773	1776	1779	1782	1785	1788	1791	1794	1797	1800	1803	1806	1809	1812	1815	1818	1821	1824	1827	1830	1833	1836	1839	1842	1845	1848	1851	1854	1857	1860	1863	1866	1869	1872	1875	1878	1881	1884	1887	1890	1893	1896	1899	1902	1905	1908	1911	1914	1917	1920	1923	1926	1929	1932	1935	1938	1941	1944	1947	1950	1953	1956	1959	1962	1965	1968	1971	1974	1977	1980	1983	1986	1989	1992	1995	1998	2001	2004	2007	2010	2013	2016	2019	2022	2025	2028	2031	2034	2037	2040	2043	2046	2049	2052	2055	2058	2061	2064	2067	2070	2073	2076	2079	2082	2085	2088	2091	2094	2097	2100	2103	2106	2109	2112	2115	2118	2121	2124	2127	2130	2133	2136	2139	2142	2145	2148	2151	2154	2157	2160	2163	2166	2169	2172	2175	2178	2181	2184	2187	2190	2193	2196	2199	2202	2205	2208	2211	2214	2217	2220	2223	2226	2229	2232	2235	2238	2241	2244	2247	2250	2253	2256	2259	2262	2265	2268	2271	2274	2277	2280	2283	2286	2289	2292	2295	2298	2301	2304	2307	2310	2313	2316	2319	2322	2325	2328	2331	2334	2337	2340	2343	2346	2349	2352	2355	2358	2361	2364	2367	2370	2373	2376	2379	2382	2385	2388	2391	2394	2397	2400	2403	2406	2409	2412	2415	2418	2421	2424	2427	2430	2433	2436	2439	2442	2445	2448	2451	2454	2457	2460	2463	2466	2469	2472	2475	2478	2481	2484	2487	2490	2493	2496	2499	2502	2505	2508	2511	2514	2517	2520	2523	2526	2529	2532	2535	2538	2541	2544	2547	2550	2553	2556	2559	2562	2565	2568	2571	2574	2577	2580	2583	2586	2589	2592	2595	2598	2601	2604	2607	2610	2613	2616	2619	2622	2625	2628	2631	2634	2637	2640	2643	2646	2649	2652	2655	2658	2661	2664	2667	2670	2673	2676	2679	2682	2685	2688	2691	2694	2697	2700	2703	2706	2709	2712	2715	2718	2721	2724	2727	2730	2733	2736	2739	2742	2745	2748	2751	2754	2757	2760	2763	2766	2769	2772	2775	2778	2781	2784	2787	2790	2793	2796	2799	2802	2805	2808	2811	2814	2817	2820	2823	2826	2829	2832	2835	2838	2841	2844	2847	2850	2853	2856	2859	2862	2865	2868	2871	2874	2877	2880	2883	2886	2889	2892	2895	2898	2901	2904	2907	2910	2913	2916	2919	2922	2925	2928	2931	2934	2937	2940	2943	2946	2949	2952	2955	2958	2961	2964	2967	2970	2973	2976	2979	2982	2985	2988	2991	2994	2997	3000
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

Fig.2. Finite element method mesh assumed for MSC NASTRAN analysis (direct graphic output)

All conductivity values, shown in Tab.1, were assumed identical to those given in [1].

Tab.1. Thermal conductivity values k [W/m · K]

Board Urethane	0.02
Foamed in Place Urethane	0.016
Plywood	0.1155
Steel	42.9

RESULTS OF CALCULATION

Some results of the calculations are shown in Fig.3 to 5 in the form of the so called XY-Plots.

A temperature distribution on warm and cold surfaces is shown in Fig.3 and 4, respectively. The „thermal bridge” effect which results from steel frame penetrating the insulation layer, can be observed on the diagrams. This effect, even much more pronounced, is visible in Fig.5 where the temperature distribution along steel flat bar frame is shown. Temperature is practically constant along the frame (due to very high conductivity of steel) but very large temperature gradient occurs in insulation layer above the frame depth. The thermal bridge effect due to steel frames dramatically affects thermal resistance of the side panel. For the considered panel it amounts only to 25% of the thermal resistance of the appropriate panel without frames, which was analyzed by using simple formulae from a textbook [3]. Thermal resistance of the panel can even drop by 70% if the insulation layer above frame is removed, i.e. only plywood liner exists above frame depth. As it follows from [1], the panel insulation effectiveness for the insulation having a thickness greater by 25 mm than the frame depth, was about two times greater than that for the insulation thickness equal to the frame depth.

Results of the heat transfer analysis are shown in Tab.2, together with the experimental and calculation results acc. to [1]. The thermal transmittance U (an overall value with surface convection effect included) is defined as follows :

$$U = \frac{q}{A(T_h - T_c)} \quad (4)$$

The panel conductance C which does not account for the surface convection, is defined as :

$$C = \frac{q}{A(T_1 - T_2)} \quad (5)$$

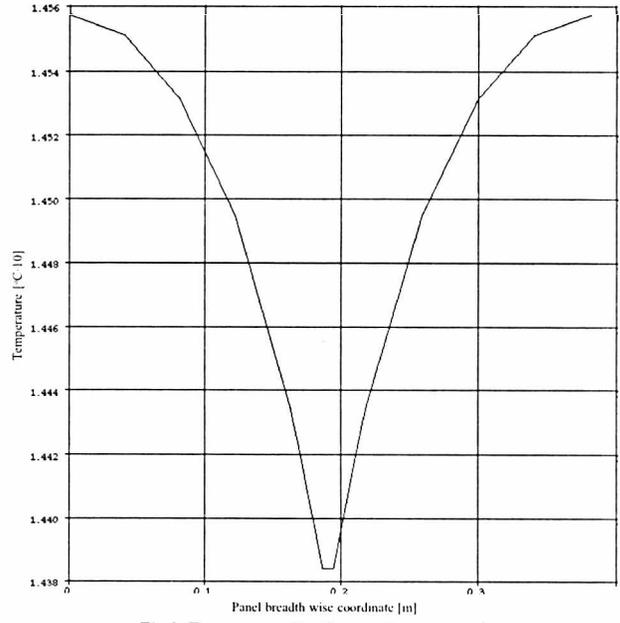


Fig.3. Temperature distribution along warm side

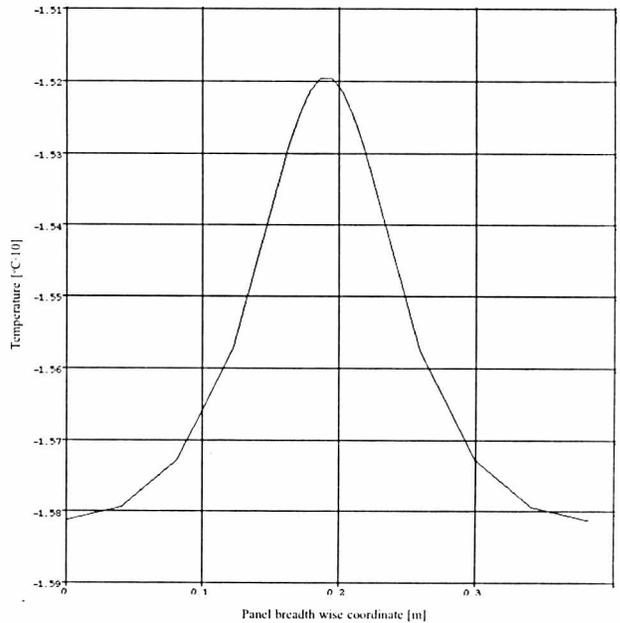


Fig.4. Temperature distribution along cold side

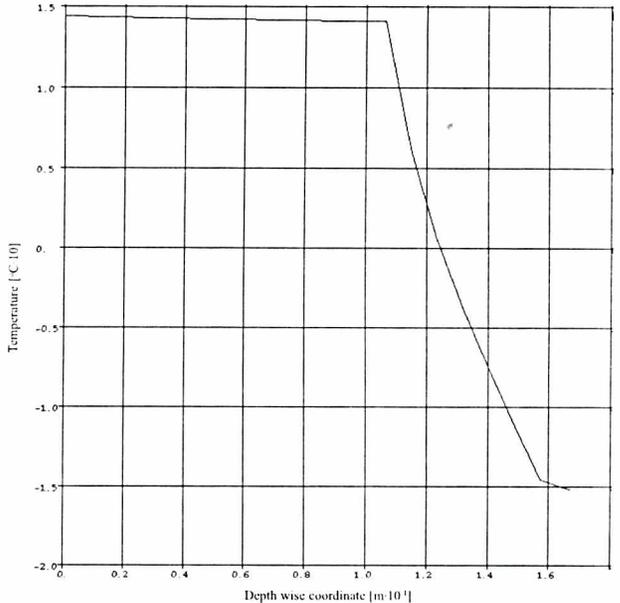


Fig.5. Temperature distribution along flat bar frame depth

Since convective resistance is different in each particular application, the thermal resistance of the panel alone, defined as :

$$R = A(T_1 - T_2)/q \quad (6)$$

is used as the calculated value. In Tab.2 calculated values of the panel resistance are compared with panel test results.

The following test conditions are assumed for MSC NASTRAN analysis, as given in Tab.2:

- warm and cold air temperature
- warm and cold surface convection coefficient.

Moreover, in the first analysis the insulation thermal conductivity of 0.02 and 0.016 is assumed, Tab.1.

Tab.2. shows that the predicted panel resistance is almost 20% greater than the test value (NASTRAN analysis No.1) while the finite difference method result [1] is greater by 5.6% only. Unfortunately, neither actual conditions nor intermediate results concerning the analysis were published. According to [1] the resistance for heat leakage calculations should be increased by about 5% to allow for the effect of steel fasteners (which are disregarded in all numerical calculations), but it is still too little to explain the significant difference between the NASTRAN analysis and test result.

3D heat flow analysis of the same side panel, but with the third dimension, $z = 890$ mm (half of the panel breadth), was performed later [4]. The convective conditions (2) were also assumed at the panel boundary $z = 890$ mm, which was equivalent to removal of any insulation from there. Results of the analysis are shown in Tab.2 as „NASTRAN analysis No.2”. This time, contrary to the 2D case, too high thermal transmittance (and too low panel resistance) is obtained, in comparison with the measurement results. This could be expected, as no heat flow was actually assumed along the boundary of $z = 890$ mm in the 2D analysis. During the experimental investigation, described in [1], some amount of heat flow probably took place because the average values from NASTRAN analysis No.1 and 2 well coincide with the measured values.

Tab.2. Test conditions and results versus numerical results

Item	Test conditions and results acc. to [1]	Numerical results acc. to [1]	NASTRAN analysis No.1 (2D case)	NASTRAN analysis No.2 (3D case*)
Heat flow rate, W/m^2	5.95		5.046	6.84
Warm air temperature, °C	15.4		15.4	15.4
Cold air temperature, °C	-16.4		-16.4	-16.4
Thermal transmittance U , W/m^2K	0.19		0.159	0.215
Area weighted average warm surface temp., °C	14.4		14.5	14.62
Area weighted average cold surface temp., °C	-15.5		-15.5	-15.82
Mean temperature of the panel, °C	-0.6		-0.5	-0.6
Warm surface convection coefficient, W/m^2K	5.62		5.62	5.62
Cold surface convection coefficient, W/m^2K	6.30		6.30	6.30
Panel conductance, C , W/m^2K	0.20	0.188	0.169	0.225
Panel resistance, R , m^2K/W	5.03	5.31	5.985	4.45

*) The convective condition (2) along the panel boundary $z = 890$ mm

CONCLUSIONS

- The thermal bridge effect due to steel frames penetrating the insulation layer dramatically affects thermal resistance of the side panel and must not be disregarded in calculations of heat leakage.

- Insulation thickness plays a very important role in the thermal performance of steel vessel wall sections. The insulation thickness equal to frame depth is critical. The best configuration is that of the insulation thickness greater by 50-60 mm than the frame depth.

- The subject of thermal conductivity of insulation needs further research because of the significant differences between the NASTRAN analysis results and both experimental and finite difference method analysis results published in [1].

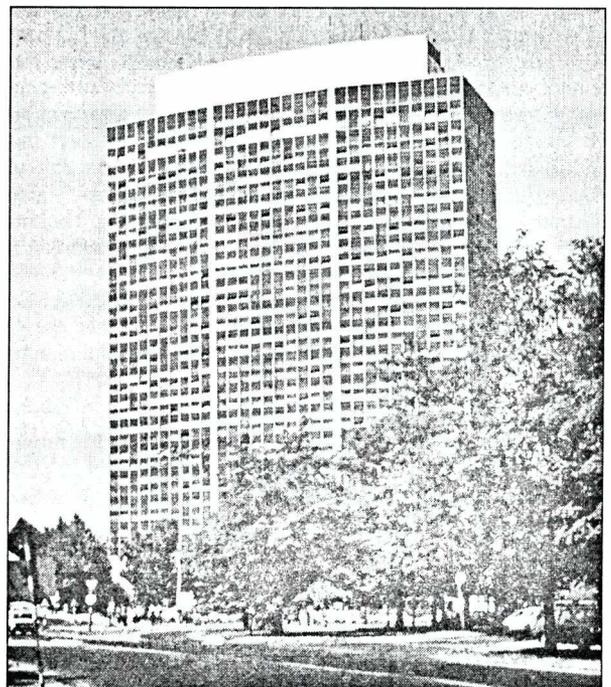
NOMENCLATURE

- A - area normal to heat flow, m^2
- C - thermal conductance, W/m^2K
- h - convection coefficient, W/m^2K
- k - thermal conductivity, W/mK
- q - heat flux, W/m^2
- R - thermal resistance of panel, m^2K/W
- R_c - contact resistance, K/W
- T - temperature, °C
- T_a - ambient temperature, °C
- T_c - average air temperature in the point 75 mm or more apart from cold surface, °C
- T_h - average air temperature, in the point 75 mm or more apart from hot surface, °C
- T_s - surface temperature, °C
- T_{s1} - area weighted average temperature of warm surface, °C
- T_{s2} - area weighted average temperature of cold surface, °C
- U - thermal transmittance of panel, W/m^2K
- x,y - Cartesian coordinates

BIBLIOGRAPHY

1. Wang D., Kolbe E.: „Prediction of Heat Leakage Through Fish Hold Wall Sections”. Journal of Ship Research, September 1989
2. Chainyk M.: „MSC NASTRAN Thermal Analysis User's Guide”. Feb. 1994
3. Holman J. P.: „Heat Transfer”. Fifth Edition, McGraw Hill Book Company, 1981
4. Buksak E., Konieczny L., Walczyk M.: „Influence of Thermal Loads on Total Stress Level in PK6105 Reefer Vessel of 650 000 cu ft Capacity - Determination of Temperature Field”. CTO Technical Report No. RK-96/T-148 (in Polish), Gdańsk 1996

Appraised by Brunon J. Grochal, Assoc. Prof., D.Sc., M.E.



The main building of Ship Design and Research Centre (CTO) in Gdańsk