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AN EVALUATION OF COBRA III-C AND SABRE-1 (WIRE WRAP VERSION) COMPUTATIONAL RESULTS BY COMPARISON WITH STEADY-STATE DATA FROM A 19-PIN INTERNALLY GUARD HEATED SODIUM COOLED BUNDLE WITH A SIX-CHANNEL CENTRAL BLOCKAGE (THORS BUNDLE 3C)*

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ABSTRACT

The predicted computational results of two well-known subchannel analysis codes, COBRA III-C and SABRE-1 (wire wrap version), have been evaluated by comparison with steady state temperature data from the THORS Facility at ORNL. Both codes give good predictions of transverse and axial temperatures when compared with wire wrap thermocouple data. The crossflow velocity profiles predicted by these codes are similar which is encouraging since the wire wrap models are based on different assumptions.

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†United Kingdom Atomic Energy Authority attache to Oak Ridge National Laboratory.

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SUMMARY

1. Introduction

Recent steady-state thermal-hydraulic test data obtained from the THORS (Thermal-Hydraulic Out-of-Reactor Safety) Facility at ORNL have been used to evaluate two well-known subchannel analysis codes. COBRA III-C[1] is in wide use in this country, while much emphasis is being placed on the development of SABRE[2,3] in the United Kingdom. Comparison of results from these codes with data from the well-instrumented THORS Bundle 3C provides a good test of the assumptions, correlations and solution methods used in the codes. Section 2 of this summary gives a direct comparison of code results and experimental temperature data, while Section 3 compares COBRA and SABRE results for wire-wrap generated subchannel to subchannel crossflow. Brief descriptions of the experimental apparatus and the computational models follow.

A cross section of THORS Bundle 3C is shown in Fig. 1. Thirty-one electric cartridge heaters (5.84 mm diameter) are spaced by wire-wraps (1.42 mm diameter) wound on a 305 mm (12 in.) pitch. The pin to pin spacing is thus 7.26 mm. Experimentally this bundle is referred to as a 19-pin bundle guard heated by 12 edge pins; for code analysis it is modeled as a 31-pin bundle. A 6.35 mm (0.25 in.) thick stainless steel plate blocks the six central flow channels 381 mm (15 in.) into the 533 mm (21 in.) heated zone. Tests on Bundle 3C were designed to measure the influence of radial temperature gradient on temperatures (and boiling, in the two phase test program) behind the blockage. The radial temperature gradient was changed by adjusting power to the twelve edge pins between 0 and 100% of central pin power.

The run chosen for analysis here is Run 111, Test 11 in which the twelve edge heaters were not powered. The power applied to the 19 central pins was 8.85 kW pin^{-1} with nominal flow conditions (7.05 ms^{-1}) at an inlet temperature of 443°C (830°F). The resulting steep radial temperature gradient poses a difficult test for COBRA and SABRE. A complete description of Bundle 3C along with experimental data may be found in Ref. 4.

The subchannel layout and gap numbering scheme used in COBRA III-C are shown in Fig. 2. SABRE uses essentially the same configuration, although subchannel and gap indexing is different. The central blockage is represented approximately in COBRA as a grid spacer resistance, while in SABRE it is represented exactly as a zero velocity boundary condition. Table 1 shows some of the more important features and input parameters of the two codes used in this analysis.

Wire wrap diversion crossflow is modeled differently in two codes - in COBRA the crossflow velocity is set to a given fraction of the axial flow (determined by wrap geometry) over a specified fraction ("DUR" in Table 1) of the axial pitch, while in SABRE crossflow results from specified resistance coefficients tangential and perpendicular to the wire wraps.

The SABRE Program was written by Imperial College, London for the United Kingdom Atomic Energy Authority (UKAEA) to provide information required for safety studies relating to the flow in a core of an LMFBR. The first version, released after substantial improvements, modifications and further developments at Atomic Energy Establishment, Winfrith (UKAEA) as SABRE-1 (Amendment 2, 1978),[2] had capabilities of modeling steady-state single phase partially blocked flows in rod cluster geometry. Recently, a physical model was formulated with explicit representation of wire wrap spacers based on Amendment 2 (1978) of SABRE-1.[3] The model assumes that the effects of wraps can be represented solely by their direction and resistance coefficients.

2. Comparison of Temperatures

COBRA and SABRE temperatures are directly compared with experimental data from steady state Run 111 of Test 11, as explained in Section 1. Both models

Table 1

	COBRA III-C	SABRE-1
Method of Solution	"Marching" solution from known inlet conditions	Iterative solution of fully three dimensional conservative equations
Blockage Representation	Resistance Coefficient	Zero velocity boundary condition
Wire Wrap Representation	Given fraction of axial flow diverted; flow area change	Axial and transverse resistance coefficients; no area change
Wire Wrap Parameters used for Run 111	DUR = .06	*Main control volume: -- $K_s = 0.24$ $K_n = 0.59$ *Lateral control volume: $K_s = 0.32$ $K_n = 140$
Mixing Parameters used in Run 111	$\beta = 0.0$ Shape factor = 1.0	FMIX = 1.0

*K_s and K_n are resistance coefficients tangential and normal to the wire wrap.

have a wire wrap representation of the complete geometry of Bundle 3C. The temperature increases above inlet are shown for two of the four diagonal transverses shown in Fig. 2, together with two axial plots (Figs. 3 through 5). The solid lines are COBRA temperatures, the dashed lines are SABRE temperatures and the individual points are experimental wire-wrap thermocouple temperatures at the indicated distance from the start of the heated section. These distances are given in inches for clarity because the wire-wrap thermocouples are at exact inch locations. There is good agreement between temperatures predicted by both codes. The profiles follow the same trends in shape and are close in magnitude, differing typically by a few degrees. Figures 3 and 4 show the close agreement in transverse temperature profile as predicted by COBRA and SABRE. Apart from a few exceptions the codes agree with the experimental data. A study of peripheral thermocouple data indicates that in the region of subchannel 32 temperatures are higher, and in the region of subchannel 28 temperatures are lower than other peripheral locations (refer to Fig. 2). This is apparent from the right hand side of both Figs. 3 and 4, respectively. Both codes predict temperatures lower than experimental data near subchannel 32 and higher near subchannel 28.

Axial temperatures for blocked subchannel 4 (Fig. 5) and unblocked subchannel 24 (Fig. 6) show excellent comparison of COBRA and SABRE. There is also consistency with wire wrap thermocouple data which is about 5°C greater than predicted at each data point. This is reasonable since the codes predict subchannel average temperatures which are in general lower than wire-wrap internal temperatures.

3. COMPARISON OF CROSSFLOW VELOCITIES

The wire-wrap forced diversion crossflow models of COBRA and SABRE are very different. Crossflow velocity profiles calculated by the two codes are compared here at the inlet flow and power conditions of Run 111 (near nominal) but without the central blockage. The same axial nodalization (2 in.) is used for both codes, and the values of the important wire wrap diversion parameters (duration of forced crossflow and resistance coefficients) are those given in Table 1.

Crossflow velocities as functions of axial position are shown in Figs. 7 and 8. Figure 7 is for internal gap 10; Fig. 8 is for edge gap 51. In general, results are surprisingly similar in behavior although they are somewhat different in magnitude. Vectors on each plot indicate position and direction of flow forcing. Note the expected oscillation in direction of crossflow velocity for the internal gap, where wire wraps come through in alternating direction every half pitch length. Results for the edge gap are somewhat surprising in that the crossflow velocity magnitude reaches a minimum at the forcing point. The fact that two models with strikingly different assumptions give results so similar in nature probably speaks well for both.

4. Summary

The steady state Run 111, Test 11 of THORS Bundle 3C has been chosen as a difficult test for COBRA III-C and SABRE-1 (wire wrap version). The experimental apparatus and details of the two models are explained. Direct comparisons of code predictions with experimental temperatures throughout the heated section of the bundle are presented. Both COBRA and SABRE temperature predictions compare well with experimental data, as shown in axial and transverse plots. The crossflow velocities predicted by these codes are similar which is encouraging since the models have very different assumptions.

REFERENCES

1. S. Rowe, COBRA III-C: A Digital Computer Program for Steady State and Transient Thermal-Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements, BNWL-1695 (1973).

2. R. Potter et al., SABRE 1 (Amendment 2) - A Computer Program for the Calculation of Three Dimensional Flows in Rod Clusters, AEEW-R 1057 Revision 2 (1978).

3. A. L. Davies and S. A. Wilkinson, The Wire Wrap Model in SABRE, AEEW-M1588, 1979.

4. N. Hanus et al., Steady-State Sodium Tests in a 19-Pin Internally Guard Heated Simulated LMFBR Fuel Assembly with a Six Channel Internal Blockage - Record of Experimental Data for THORS Bundle 3C, ORNL/TM-6498 (to be published).

Figure Captions

Figure 1. Cross section of THORS Bundle 3C. ORNL-DWG 77-6517RB2.

Figure 2. COBRA III-C model of THORS Bundle 3C. ORNL-DWG 78-22170.

Figure 3. Radial transverse 1. ORNL-DWG 78-22171.

Figure 4. Radial transverse 2. ORNL-DWG 78-22172.

Figure 5. Axial plot of subchannel 4. ORNL-DWG 78-22175.

Figure 6. Axial plot of subchannel 24. ORNL-DWG 78-22176.

Figure 7. Crossflow velocity in gap 10. ORNL-DWG 78-22177.

Figure 8. Crossflow velocity in gap 51. ORNL-DWG 78-22179.

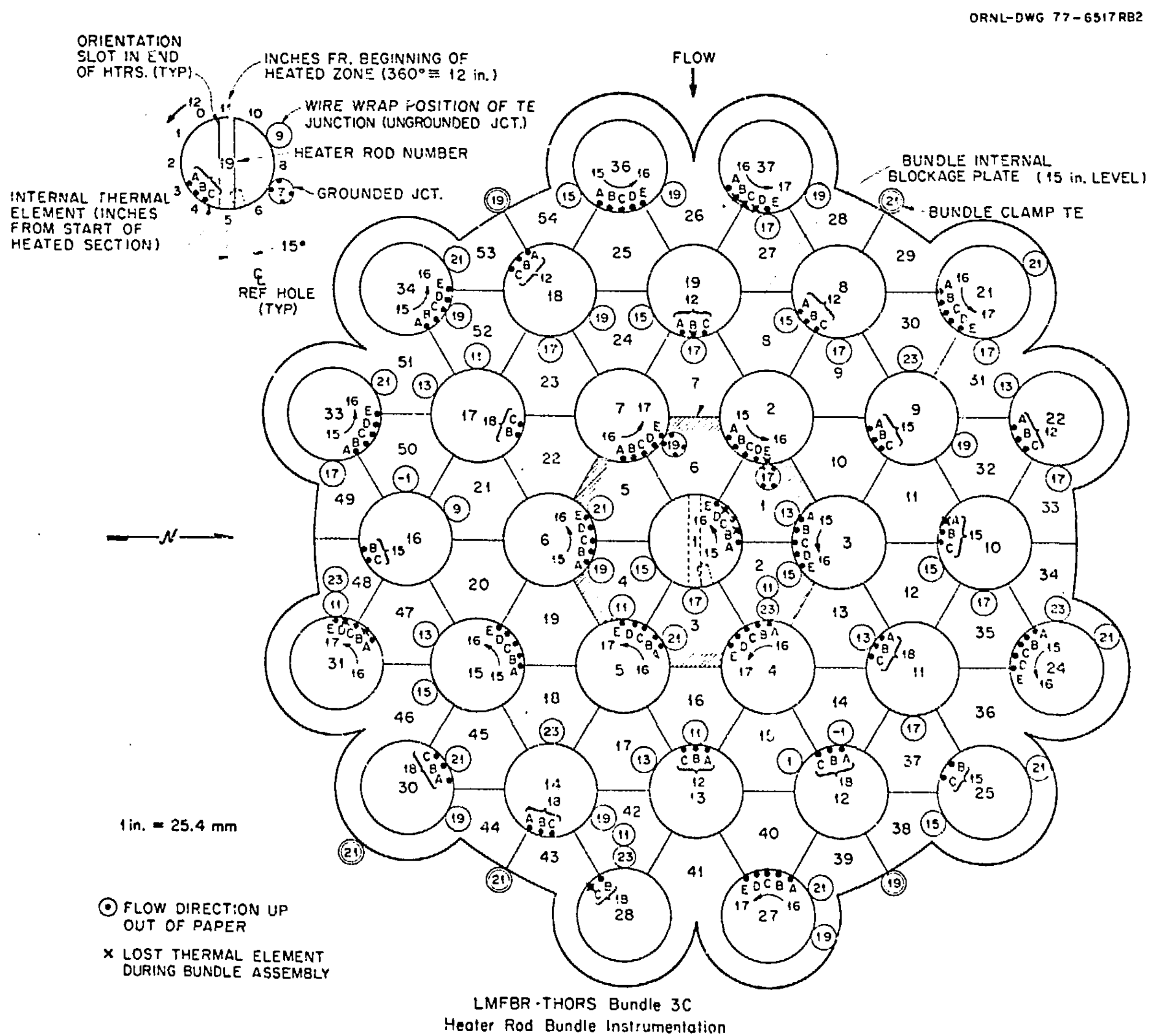

Figure 1. Cross section of THORS Bundle 3C.

ORNL DWG 78 22170

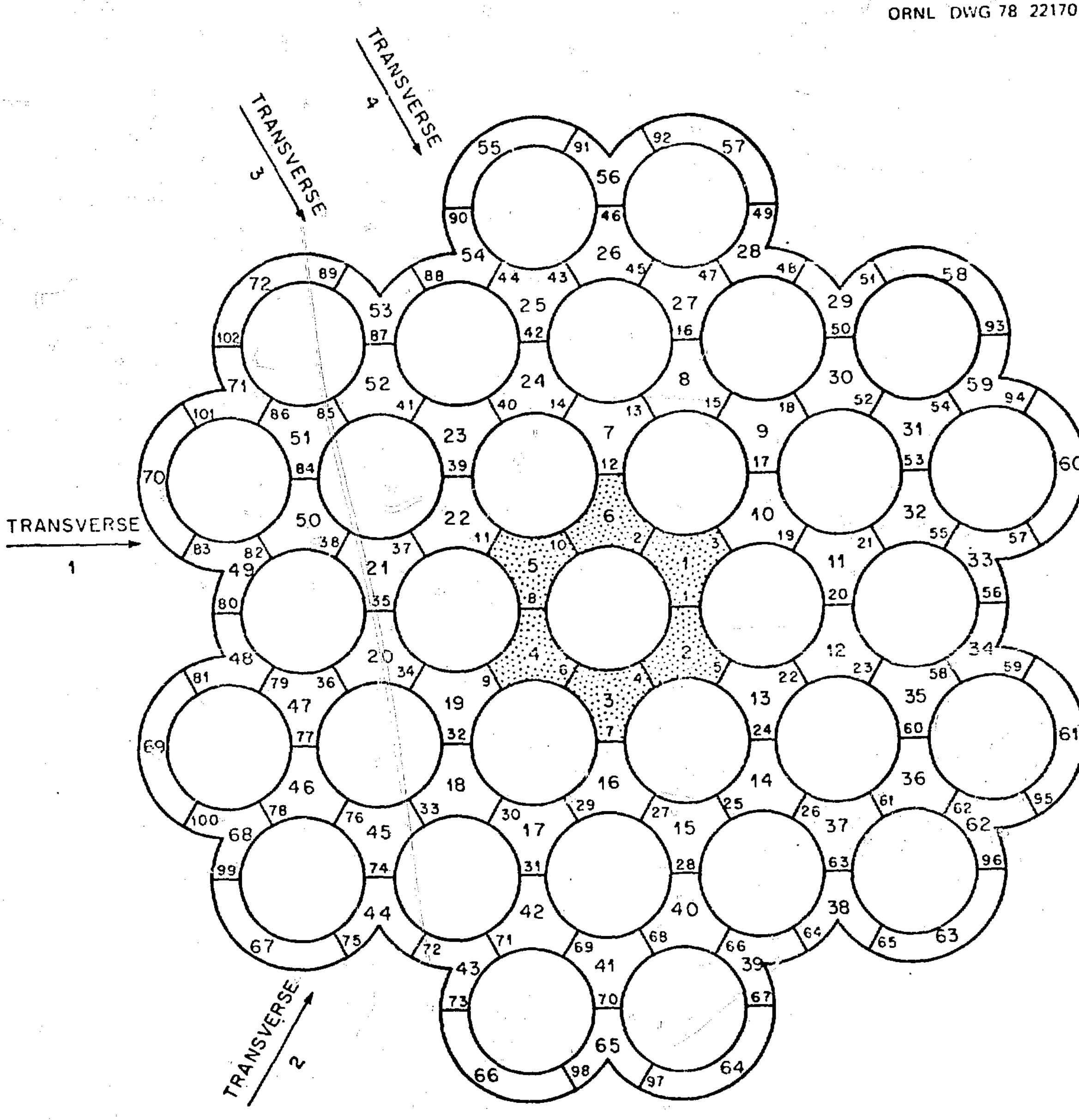

Figure 2. COBRA III-C model of THORS Bundle 3C.

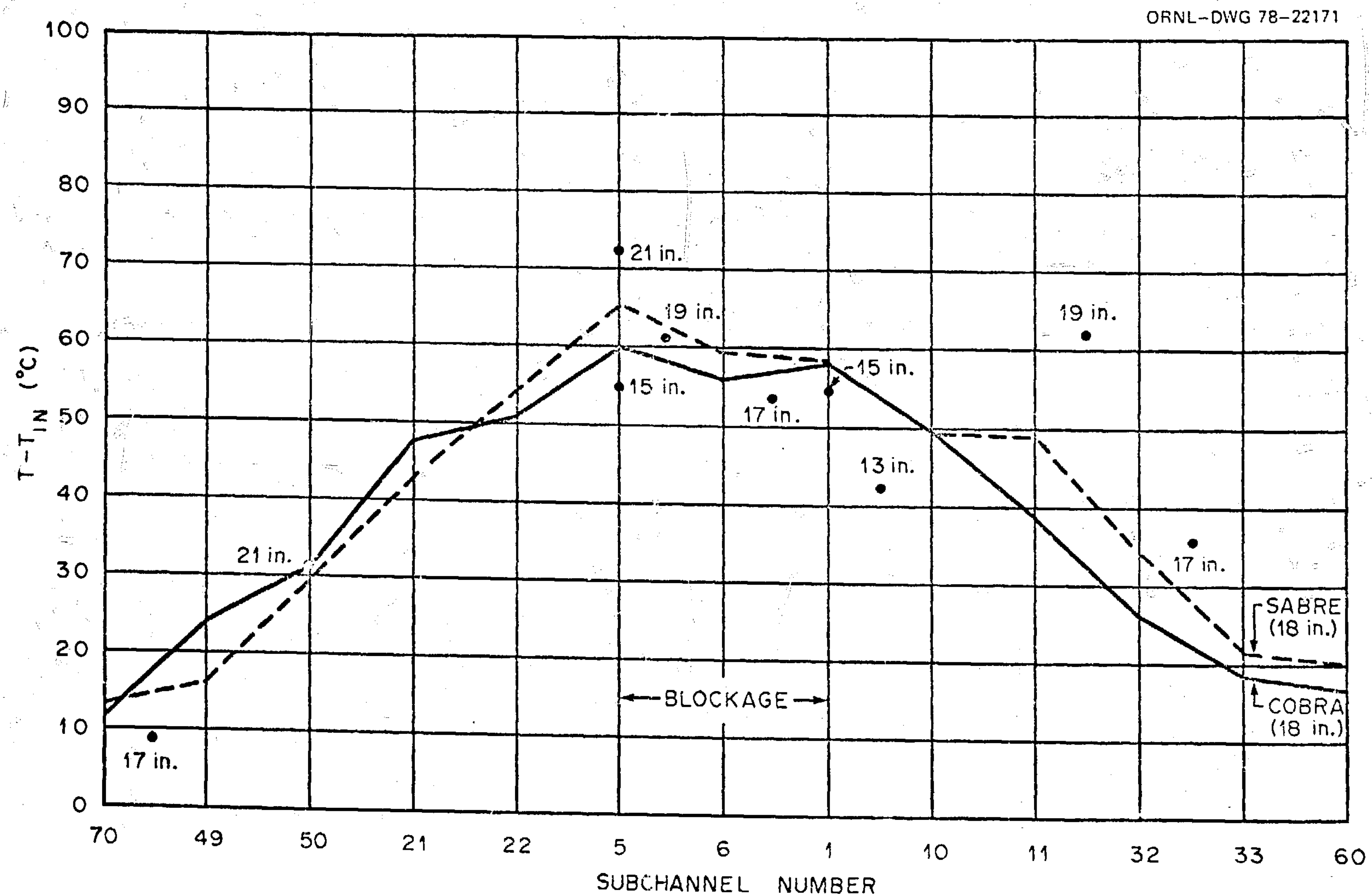

Figure 3. Radial transverse 1.

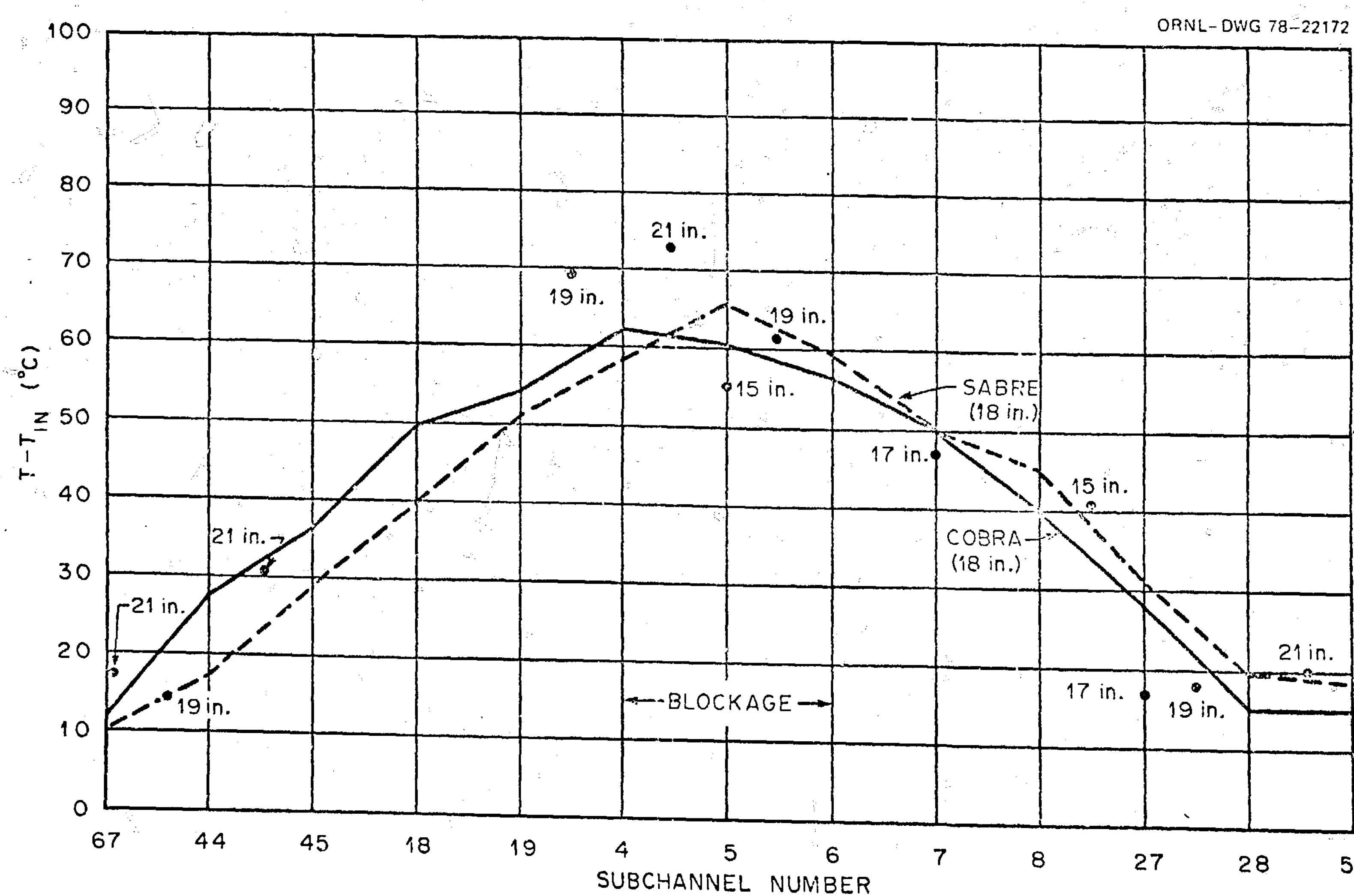

Figure 4. Radial transverse 2.

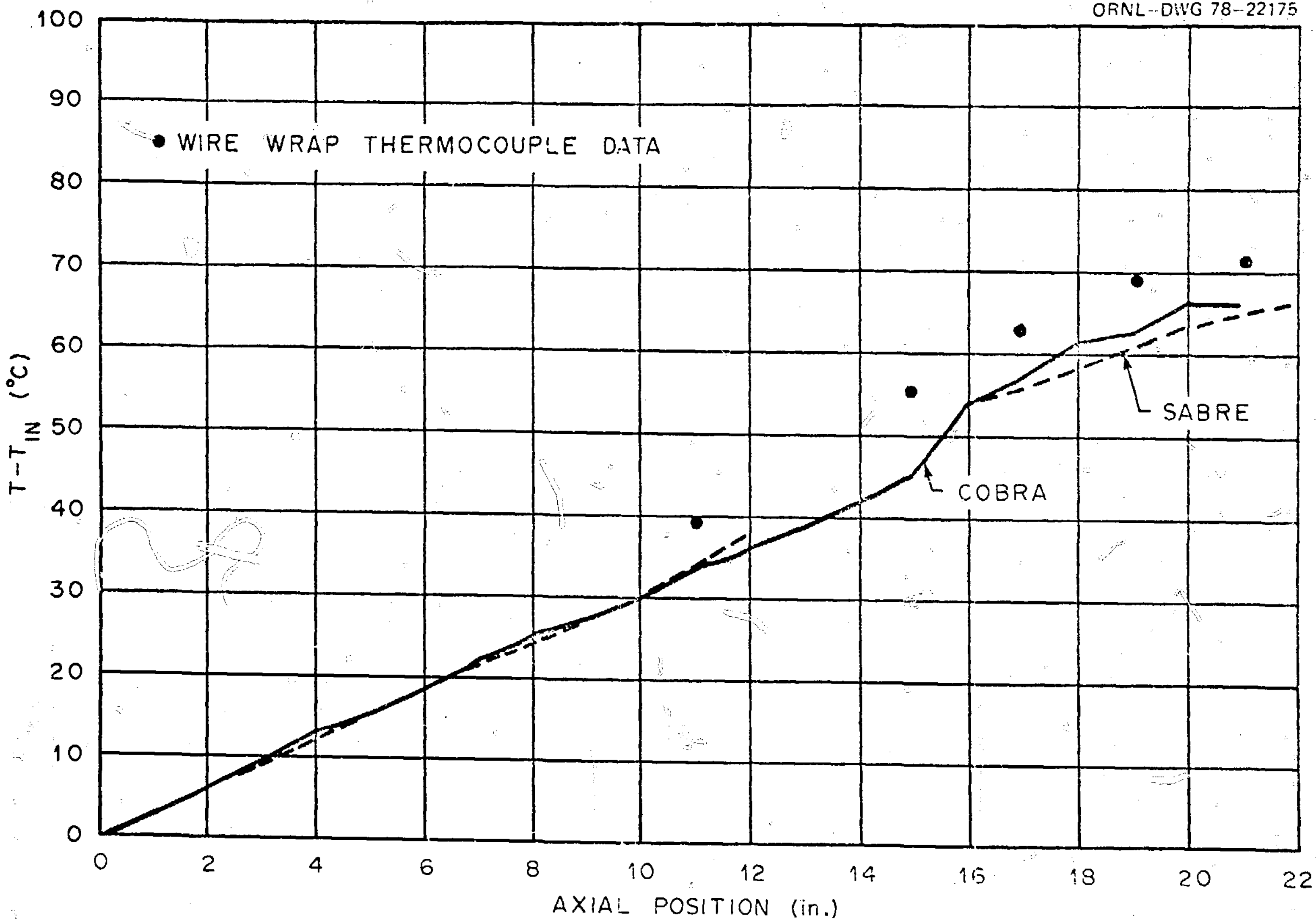

Figure 5. Axial plot of subchannel 4.

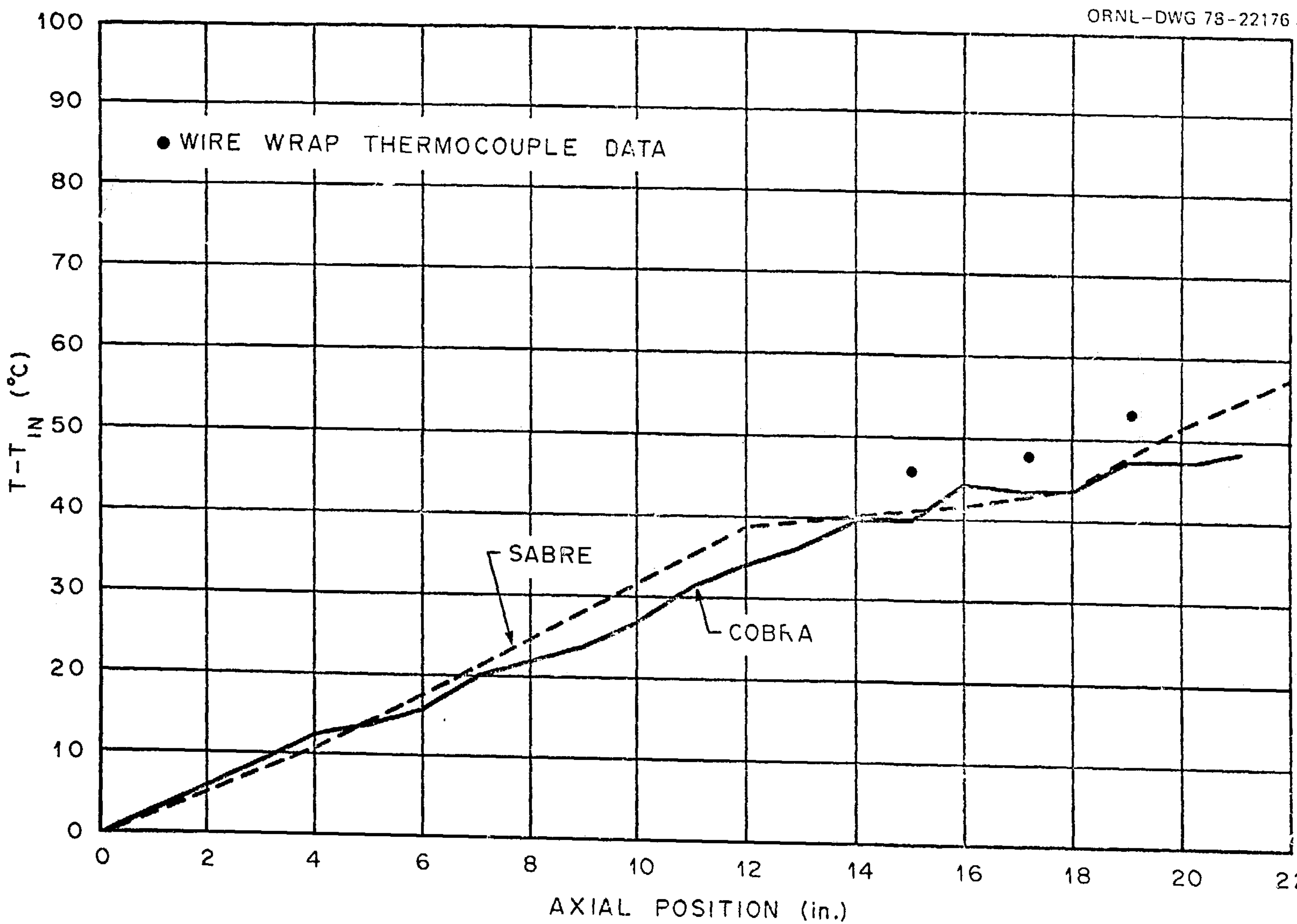

Figure 6. Axial plot of subchannel 24.

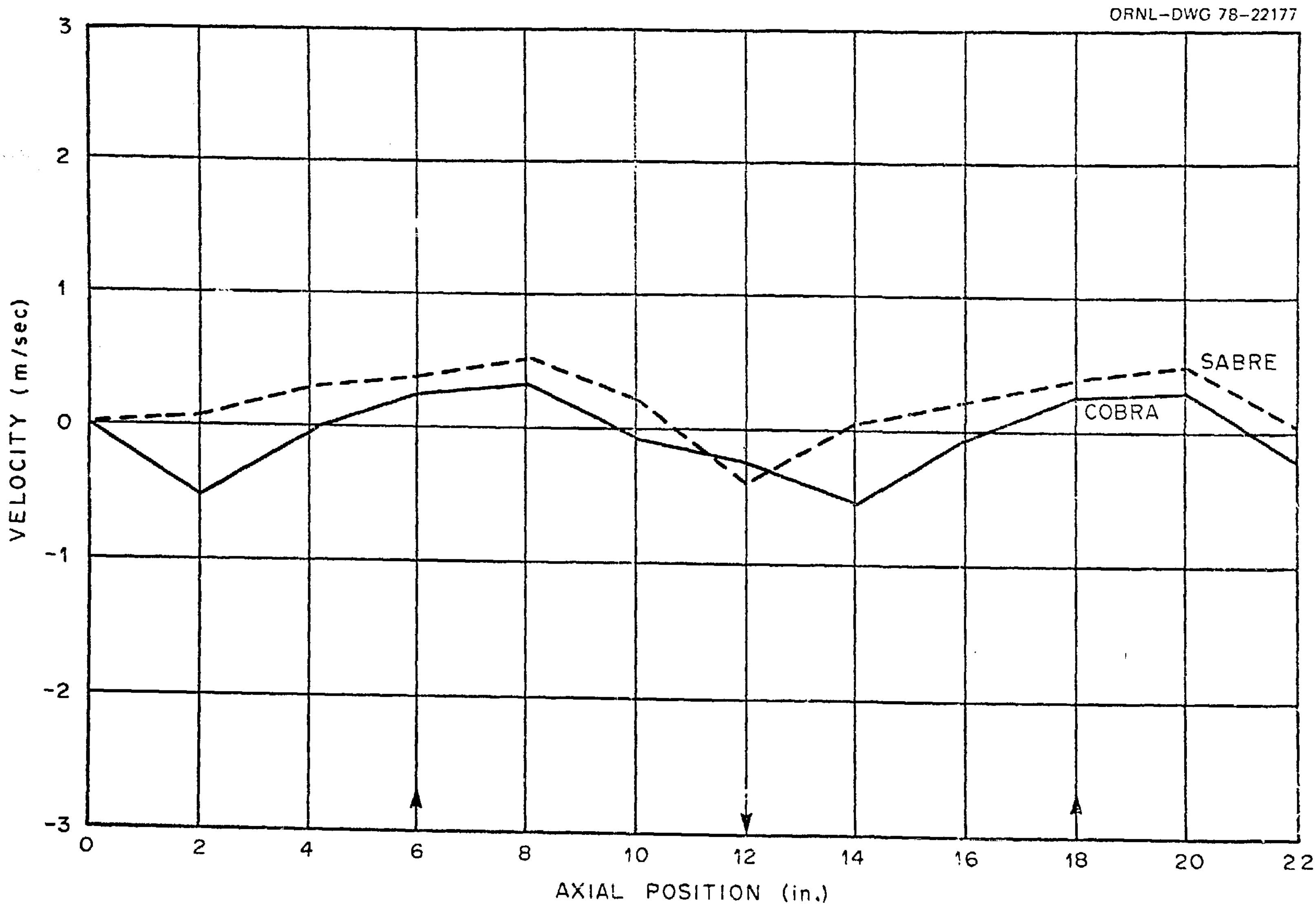

Figure 7. Crossflow velocity in gap 10.

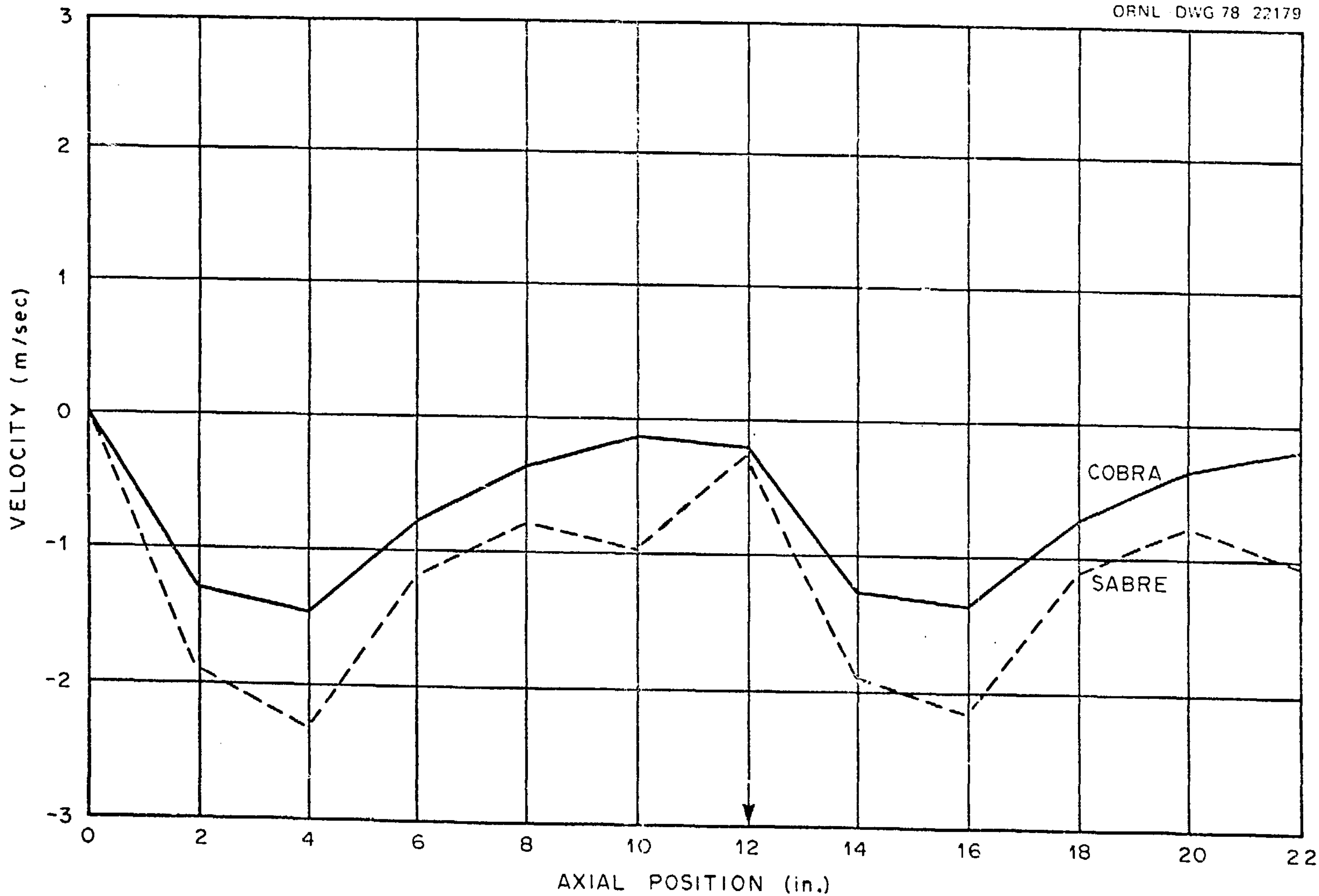

Figure 8. Crossflow velocity in gap 51.