High Efficiency Cryocooler Performance

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ABSTRACT

The Northrop Grumman TRL 9 High Efficiency Cryocooler (HEC) is a pulse tube cryocooler with flexure bearing compressor that has been delivered for flight for a number of different payloads while configured for a variety of cold head temperatures and cryogenic loads extending from 35 K to 200 K. The coolers have been customized for many of the payloads either in one or two-stage configurations by optimizing the cold heads for temperature and load or with linear or coaxial cold heads or both. Common to all of these coolers is the compressor and flight electronics. The performance of some of these various coolers has previously been published. Recently we have extended the performance of the single stage coolers to much higher cooling power and to lower temperatures, and improved the performance of the coaxial cold head integral cooler. This paper describes the performance of these HEC coolers over their complete range of capability.

INTRODUCTION

The small High Efficiency pulse tube Cooler (HEC) shown in Figure 1 has been produced and flown on a number of space infrared instruments in one and two-stage configurations with a number of different pulse tube cold heads that in many cases were customized for the mission cooling requirements. The mechanical cooler was originally designed and optimized in 1999 to provide cooling of 10 W at 95 K while rejecting to 300 K using its proprietary balanced flexure bearing compressor and a linear pulse tube cold head.[1,2] Flight units were first delivered in 2002. The

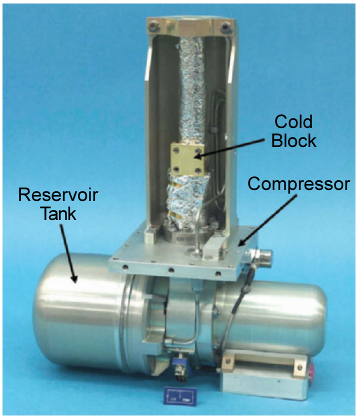

Figure 1. Integral vibrationally balanced HEC pulse tube cooler

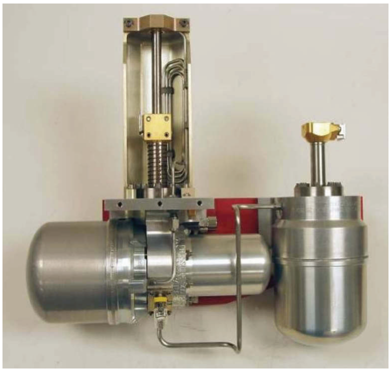

Figure 2. Two-stage HEC pulse tube Cryocooler

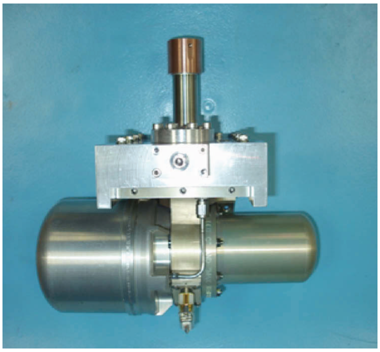

Figure 3. Integral single stage pulse tube cooler with coaxial cold head

Japanese Advanced Meteorological Imager (JAMI)[3] hosted the first two of these units to fly in 2005 and they have been performing nominally without degradation since that time. The large number of flight units that have been delivered have maintained the same compressor design but have included in some cases customized cold heads in order to optimize performance for individual payload cooling requirements. Typically these minor changes have included customized regenerators and inertance lines in order to optimize performance at given temperatures or at specified operating frequencies. These customized single stage cold heads have been optimized for efficient performance at temperatures as low as 40 K. As an example, a specific power of 60W/W has been achieved at 45K for a rejection at 300K. This flight cooler configuration has also been incorporated as one stage of a two-stage cooler[4] by adding a second split coaxial cold head driven through a transfer line attached to the compressor (Figure 2). This 2-stage configuration provides the capability to either cool two focal planes or to cool one focal plane to temperatures as low as 35 K while simultaneously cooling optics or shielding at higher temperatures.

A third flight cooler configuration is one in which the linear cold head is replaced by a coaxial cold head as shown in Figure 3. In addition to the numerous flight units delivered we have also tested both one and 2-stage engineering models that have been customized for specific applications.[5] These include single stage coolers[6] with a very large cooling power at 150 K with both linear and coaxial cold heads. These higher cooling powers in such a low mass cryocooler are motivated by the advent of very large focal plane arrays. The cooler operating at 290W input power achieves 35W at 150 K corresponding to a specific cooling power at 150 K of 8.25 W/W and a very high specific mass of 72.5 W/kg.

For all of these flight coolers, 20 first-generation flight Cryocooler Control Electronics (CCE) and 26 current smaller lower mass 2nd generation Advanced Cryocooler Control Electronics (ACE) (as shown in Figure 4) have been delivered. For the largest cooling capacity of the HEC cooler[6] the flight control electronics shown in Figure 5 can be used.

Figure 4. ACE Flight Electronics: 180W maximum output capacity

Figure 5. DEUCE Flight Electronics: 360W maximum output capacity

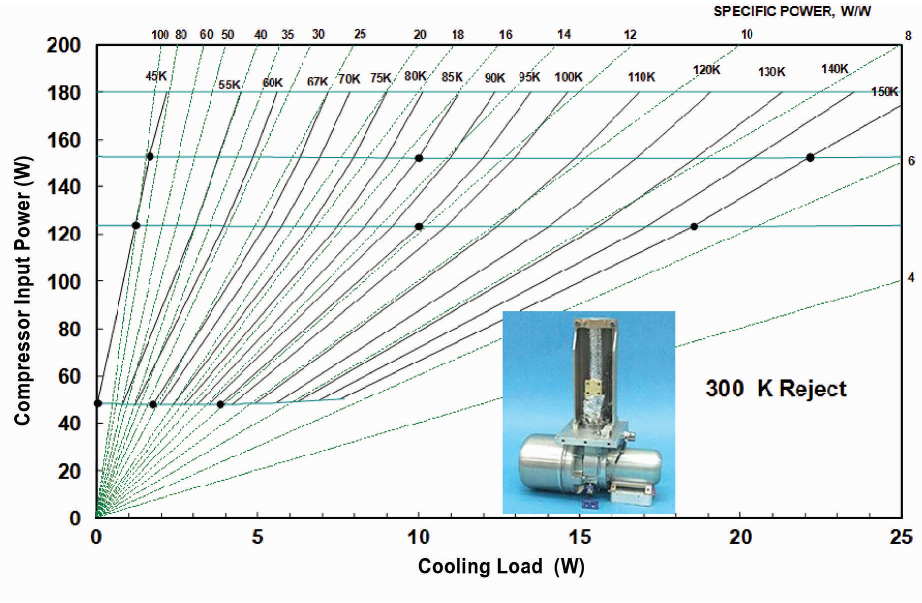

Figure 6. Performance of single-stage flight model HEC cooler with linear cold head optimized for 95 K operation and 300 K reject temperature

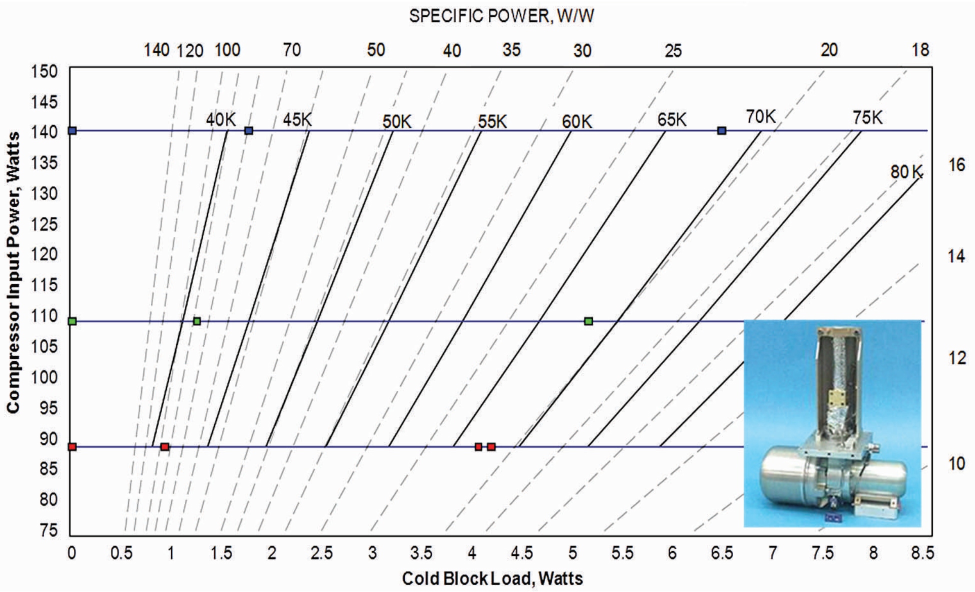

Figure 7. Performance of single-stage flight model HEC cooler with linear cold head optimized for 45 K operation and 300 K reject temperature.

PERFORMANCE

In this section we present both previously published and unpublished data acquired for these coolers. The performance of various of these single stage coolers with linear cold heads is summarized in Figures 6, 7, 8, 9, and 10. For clarity a picture of the cooler type is shown with each graph.

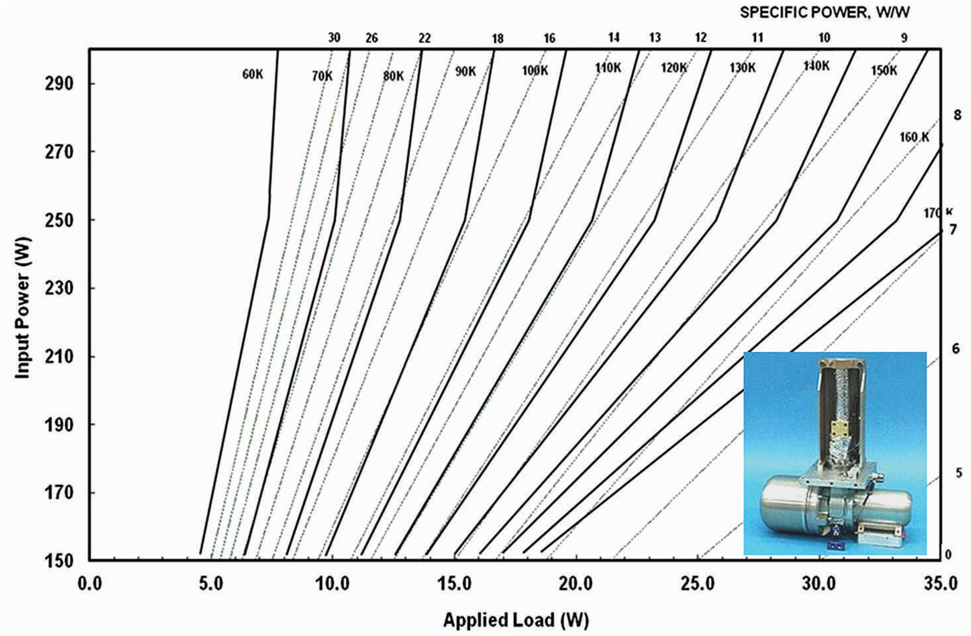

Figure 8. Performance of high power single stage HEC cooler with linear cold head optimized for 150 K operation and 300 K reject temperature.

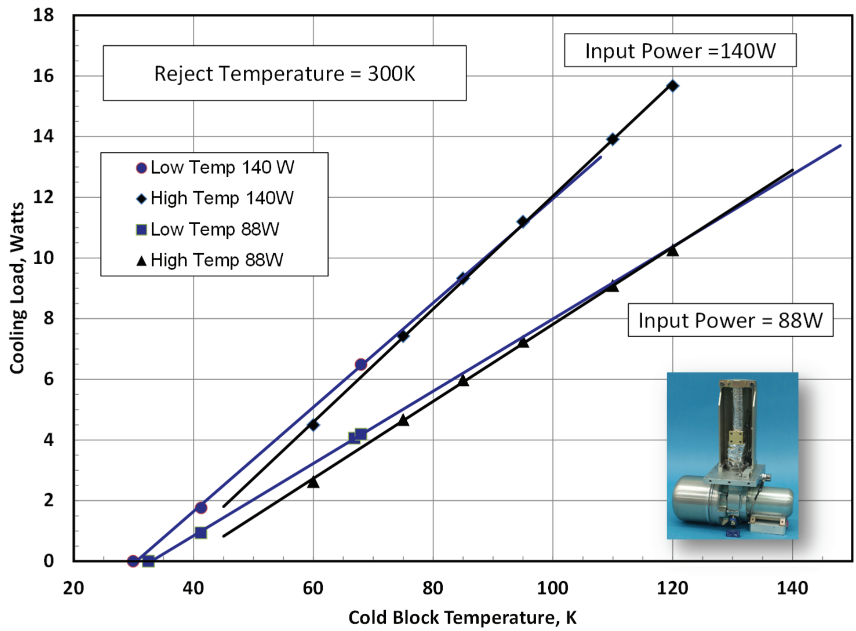

Figure 9. HEC linear single stage coolers with cold heads optimized for either high or low temperatures.

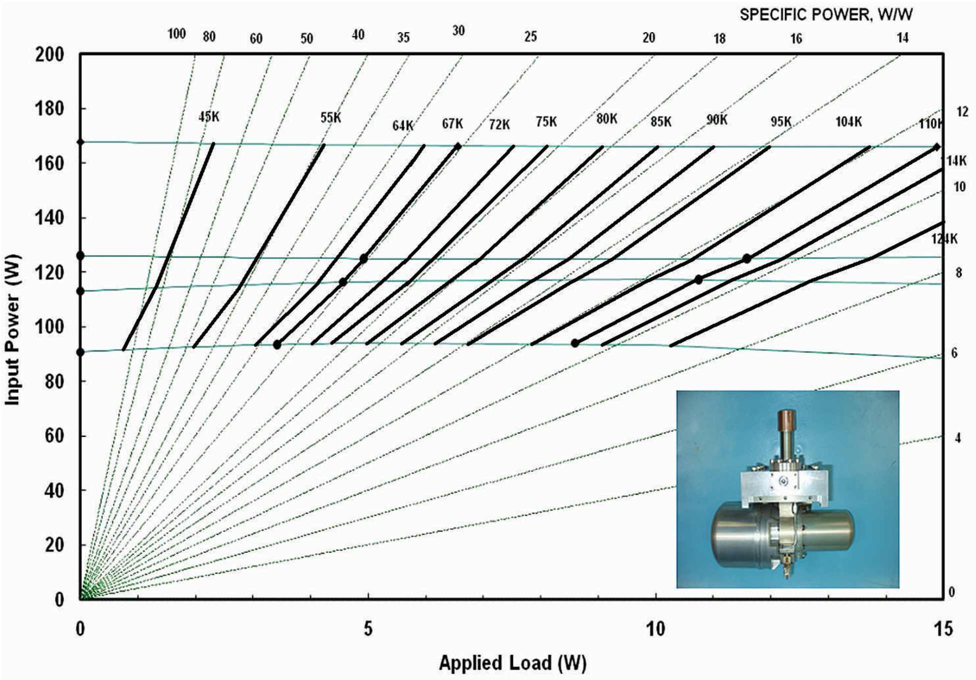

Figure 10. Performance of single stage flight model HEC cooler with coaxial cold head

In Figure 10 we also present performance data for an integral version of the previous cooler but with a coaxial pulse tube cold head. We have also delivered flight coolers with this configuration.

In addition to the cooling performance, a number of other properties of these cryocoolers are usually important once they are integrated into payloads. The self-induced vibration of these coolers[7] that is produced by the balanced moving masses in the compressor as well as the moving gas mass in the completely passive pulse tube cold head can give rise to vibration output. As shown in Figure 11, vibration measurements were taken for the linear cold head cooler shown in Figure 1 with the cooler hard mounted to a dynamometer with closed loop control of the vibration along the compressor drive axis (y-axis). The vibration data shown in Figure 12 describe the capability of the system under a rigid mounting boundary condition. Similar measurements were previously reported[7] with the cooler hung from a bungee cord to provide a second free body boundary condition. In use on a real payload the cryocooler is mounted to a structure that has neither of these ideal interfaces.

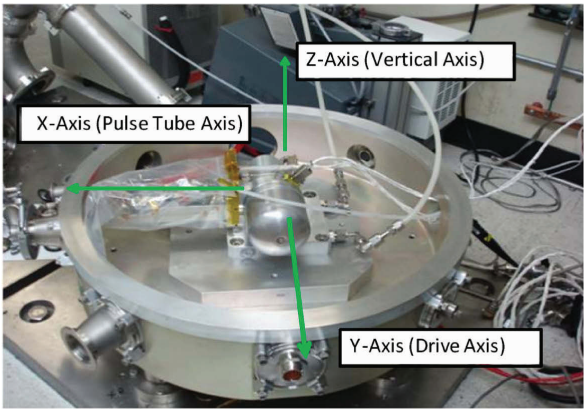

Figure 11. Vibration output of HEC linear cold head cooler hard mounted to dynamometer

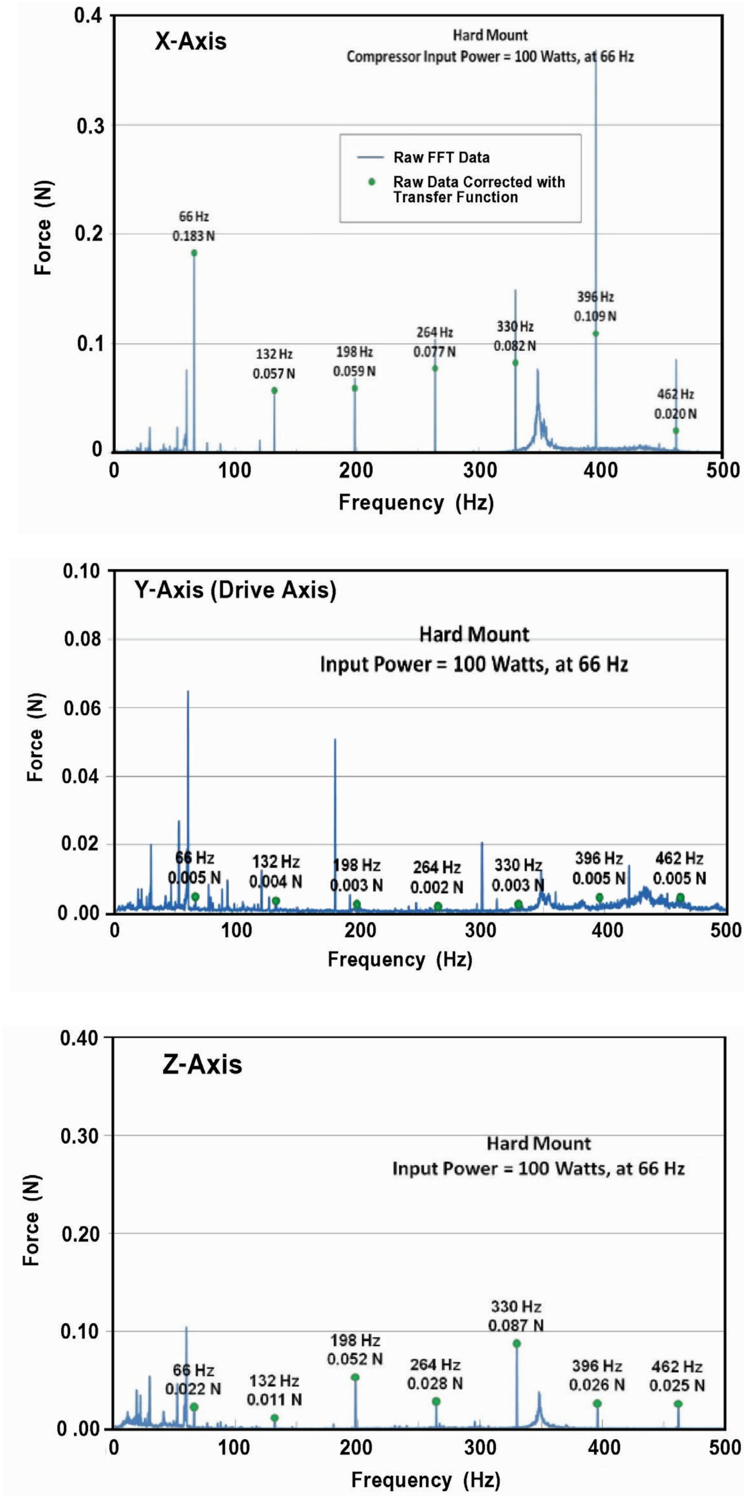

Figure 12. Vibration output of HEC linear cold head cooler hard mounted to dynamometer

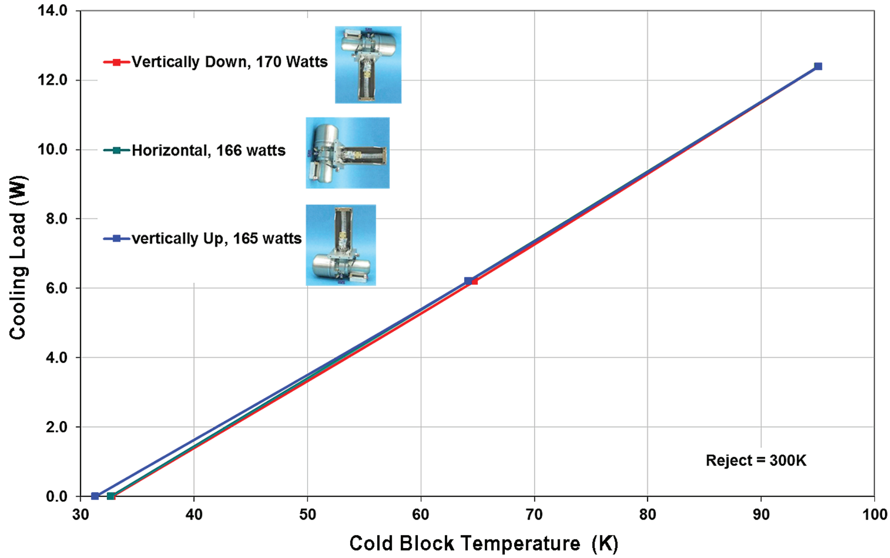

Figure 13. Effect of orientation on cooler load lines

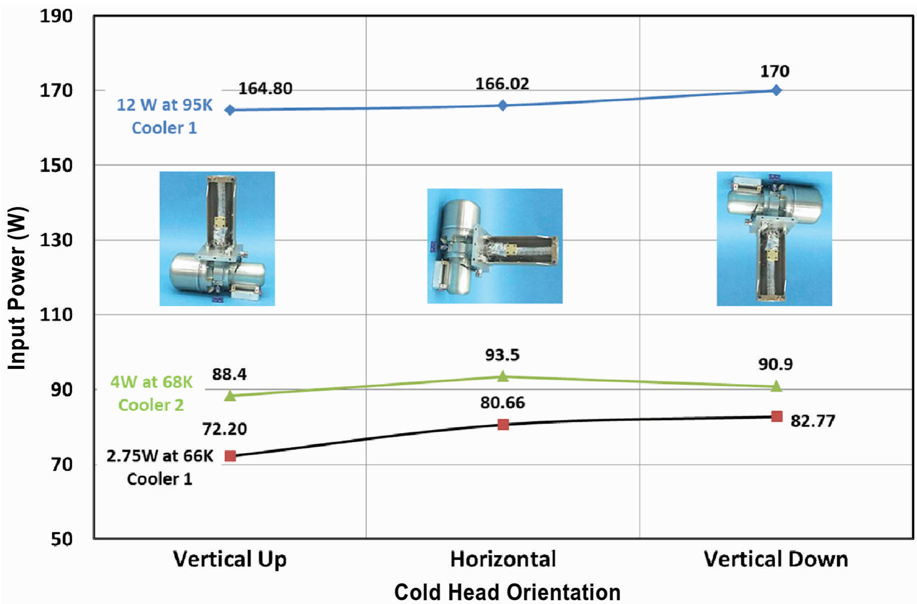

Figure 14. Effect of orientation on cooler performance as a function of input power

Pulse tube cooler performance is also sensitive to orientation relative to gravity that for these space cryocoolers matters only during testing on Earth. This arises because of the possibility of convection cells in the pulse tube that is an empty pipe with a large temperature gradient. The effect is relatively small for this cryocooler by design. Figure 13 illustrates the relatively small gravity orientation sensitivity (~5%) when the cooler is operating at higher powers. The vertically up orientation is equivalent to its performance in space since the pulse tube warm end is directly above the pulse tube cold block. Figure 14 illustrates the effect as a function of input power for two different coolers of the same design.

CONCLUSION

A number of the small HEC flight pulse tube coolers has been produced and flown on space infrared instruments in one and two-stage configurations with a number of different pulse tube cold heads. The compressor and flight electronics are common components that have been reused for these flight coolers that have been customized for mission cooling requirements with different cold heads. Coolers of this family have been in orbit performing nominally since 2005.

ACKNOWLEDGEMENT

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