THE MARS 2020 ROVER ENGINEERING CAMERAS. J. N. Maki[1], C. M. McKinney[1], R. G. Willson[1], R. G. Sellar[1], D. S. Copley-Woods[1], M. Valvo[1], T. Goodsall[1], J. McGuire[1], K. Singh[1], T. E. Litwin[1], R. G. Deen[1], A. Culver[1], N. Ruoff[1], D. Petrizzo[1], [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109, Justin.N.Maki@jpl.nasa.gov).

Introduction: The Mars 2020 Rover is equipped with a next-generation engineering camera imaging system that represents a significant upgrade over the previous Navcam/Hazcam cameras flown on MER and MSL [1,2]. The Mars 2020 engineering cameras acquire color images with wider fields of view and higher angular/spatial resolution than previous rover engineering cameras. Additionally, the Mars 2020 rover will carry a new camera type dedicated to sample operations: the Cachecam.

History: The previous generation of Navcams and Hazcams, known collectively as the engineering cameras, were designed in the early 2000s as part of the Mars Exploration Rover (MER) program. A total of 36 individual MER-style cameras have flown to Mars on five separate NASA spacecraft (3 rovers and 2 landers) [1-6]. The MER/MSL cameras were built in two separate production runs: the original MER run (2003) and a second, build-to-print run for the Mars Science Laboratory (MSL) mission in 2008. Newer technologies and electronics parts obsolescence have brought the MER/MSL camera production to a close, with no additional production runs planned. The Mars 2020 MEDA SkyCam [7] will likely be the last MER/MSL camera to fly to Mars (the SkyCam utilizes a flight spare Hazcam from MSL).

Instrument Functional Description: The Navcams provide stereo image data for rover traverse planning, targeting of remote sensing instruments, operation of the robotic arm, and the acquisition of panoramas with a 360° field of regard around the rover. The Hazcams acquire context images immediately forward and aft of the rover (in particular the areas not viewable by the Navcams) for traverse planning, robotic arm operations, support for rover fine positioning, and imaging of the front and rear wheels. Both the Navcam and Hazcam cameras provide stereo image data to the rover autonomous navigation system. The Cachecam, a new type of rover camera, will document sample handling operations inside the rover sample caching system (SCS).

Instrument Description

The Mars 2020 engineering cameras incorporate heritage design principles from MER/MSL: 1) small, ruggedized camera bodies with fixed-focus lenses, 2) a simple camera head with limited processing and storage capabilities (image storage and compression functions are performed separately, by the spacecraft/rover computer) and 3) cameras mounted together as stereo pairs (the Cachecam, a monoscopic camera, is an exception). The Mars 2020 engineering cameras are packaged into a single, compact camera head (see figure 1).

Figure 1. Flight Navcam (left), Flight Hazcam (middle), and flight Cachecam (right). The Cachecam optical assembly includes an illuminator and fold mirror.

Each of the Mars 2020 engineering cameras utilize a 20 megapixel OnSemi (CMOSIS) CMOS sensor equipped with a Bayer pattern RGB color filter array. The Mars 2020 Navcams, mounted on the pan/tilt Remote Sensing Mast (RSM), will acquire color stereo images (figure 2) and panoramas from a height of approximately 2 meters above the Martian surface (figure 3). The Mars 2020 Hazcams are hard-mounted to the rover body at a height of approximately 0.7 meters above the surface (figure 3) and will acquire color stereo images of the areas immediately in the front and rear of the rover. The Cachecam will acquire color images of sample materials as they are being processed by the Mars 2020 Sample Caching System (figure 4).

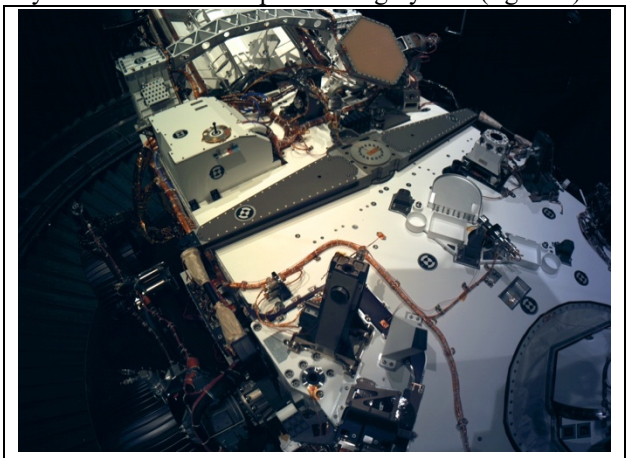

Figure 2. Single frame Navcam image of the Mars 2020 flight rover deck, acquired during system thermal vacuum testing in October 2019.

Table 1. Mars 2020 Engineering Camera Summary

Sensor Capabilities	
Type	20 MegaPixel CMOS
Optical Format	35 mm
Array Size	5120 x 3840 pixels
Pixel Size and Pitch	6.4 microns
Full well charge	15,000 e^-
Pixel Dark Noise	8 e^- RMS
Pixel Dark Current	125 e^-/s @ 25C
Windowing	Region of Interest (ROI)
Shutter	Global
Pixel Quantization	12 bits
Electrical Interface	
Commanding & Data	LVDS
Protocol	MER/MSL/Mars2020 NVMCAM
Power Input	+5 V (+/- 0.5 V)
Power	< 10 W
Memory	1 Gbit SDRAM
Non-Volatile FPGA	MicroSemi Rad-Tolerant ProASIC3
Camera System Specifications	
Mass (CBE, no optics)	[< 425 g]
Volume (CBE, no optics)	[75 mm x 85 mm x 55 mm]
Operating Temperature	-55C to +50C
Survival Temperature	-135C to +70C
Mars2020 Optics Configurations	
Navigation Camera (Color)	FOV = 96° X 73°(H x V), f/12, IFOV = ~ 0.33 mrad 42.4 cm stereo baseline
Hazard Camera (Color)	FOV = 136° X 102°(H x V), f/12, IFOV = ~ 0.45 mrad
Sample Camera (Color)	EFL = ~ 30mm, Focus Distance = 270mm, f/8

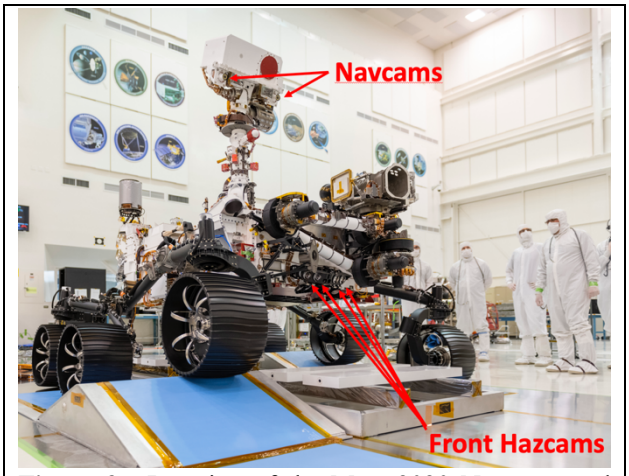

Figure 3. Location of the Mars 2020 Navcams and Front Hazcams. The Cachecam camera is located insided the rover body.

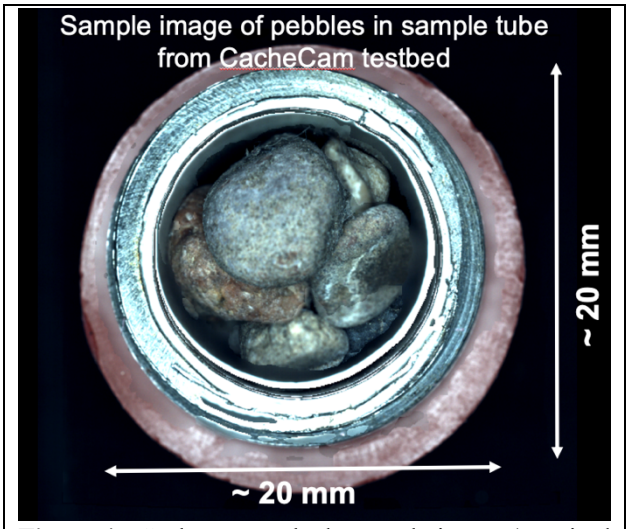

Figure 4. Cachecam testbed example image (acquired from a prototype camera).

Current Status: The Mars 2020 engineering cameras were delivered to the Mars 2020 project in the mid-2019 and integrated onto the rover shortly thereafter. The cameras have completed a variety of system tests in Mars 2020 ATLO, including thermal vacuum testing and geometric camera calibration. Performance of the cameras has been nominal during this period. Final prelaunch closeout imaging testing is scheduled for March of 2020. For a full description of the Mars 2020 engineering cameras, see [8]. The Mars 2020 launch window opens on July 17th, 2020, with landing on Mars scheduled for February 18th, 2021.

References:

[1] Maki, et al (2003) The Mars Exploration Rover Engineering Cameras, J. Geophys. Res., 108(E12), 8071. [2] Maki, et al, (2012), The Mars Science Laboratory engineering cameras, Space Sci. Rev., 170:77-93. [3] Bell et al. (2003), Mars Exploration Rover Athena Panoramic Camera (Pancam) Investigation, J. Geophys. Res., 108(E12), 8063, [4] Herkenhoff et al (2003), Athena Microscopic Imager Investigation, J. Geophys. Res., 108(E12), 8065, [5] Lemmon, et al (2008), The Phoenix Surface Stereo Imager (SSI) Investigation, 39th LPSC XXXIX, No. 1391. [6], Maki et al. (2018), The Color Cameras on the InSight lander, Space Sci. Rev. 214:105. [7] Lemmon et al., LPSC 51 (this conference), [8] Maki et al., to be submitted to Space Sci. Rev., 2020.

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