lower temperatures can be used in the heat treatment process, less energy will be consumed, and there will be less dimensional distortion and quench cracking. This results in fewer scrap parts, less material waste from large amounts of material removal, and fewer machining steps to rework parts that are out of specification.

This material has a combination of properties that have been previously unobtainable. The material has a Young's modulus of approximately 95 GPa (about half that of conventional steels), moderate density (10 to 15% lower than conventional steels), excellent corrosion resistance, and high hardness (58 to 62 HRC). These properties make this material uniquely suited for advanced bearings.

This work was done by Malcolm Stanford, Ronald Noebe, Christopher Dellacorte, Glen Bigelow, and Fransua Thomas of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19029-1. t

Cu-Cr-Nb-Zr Alloy for Rocket Engines and Other High-Heat-Flux Applications

Applications include high-temperature, high-efficiency industrial heat exchangers, welding electrodes, and head gaskets for automobile racing engines.

John H. Glenn Research Center, Cleveland, Ohio

Rocket-engine main combustion chamber liners are used to contain the burning of fuel and oxidizer and provide a stream of high-velocity gas for propulsion. The liners in engines such as the Space Shuttle Main Engine are regeneratively cooled by flowing fuel, e.g., cryogenic hydrogen, through cooling channels in the back side of the liner. The heat gained by the liner from the flame and compression of the gas in the throat section is transferred to the fuel by the liner. As a result, the liner must either have a very high thermal conductivity or a very high operating temperature.

In addition to the large heat flux (>10 MW/m^2), the liners experience a very large thermal gradient, typically more than 500 °C over 1 mm. The gradient produces thermally induced stresses and strains that cause low cycle fatigue (LCF). Typically, a liner will experience a strain differential in excess of 1% between the cooling channel and the hot wall. Each time the engine is fired, the liner undergoes an LCF cycle. The number of cycles can be as few as one for an expendable booster engine, to as many as several thousand for a reusable launch vehicle or reaction control system. Finally, the liners undergo creep and a form of mechanical degradation called thermal ratcheting that results in the bowing out of the cooling channel into the combustion chamber, and eventual failure of the liner.

GRCop-84, a Cu-Cr-Nb alloy, is generally recognized as the best liner material available at the time of this reporting. The alloy consists of 14% Cr_2Nb precipitates in a pure copper matrix. Through experimental work, it has been established that the Zr will not participate in the formation of Laves phase precipitates with Cr and Nb, but will instead react with Cu to form the desired Cu-Zr compounds. It is believed that significant improvements in the mechanical properties of GRCop-84 will be realized by adding Zr. The innovation is a Cu-Cr-Nb-Zr alloy covering the composition range of 0.8 to 8.1 weight percent Cr, 0.7 to 7.2 weight percent Nb, 0.1 to 1.5 weight percent Zr, and balance Cu.

The alloy combines two known strengthening mechanisms — dispersion strengthening by Cr_2Nb precipitates (GRCop-84), and precipitation strengthening by Cu_xZr (AMZIRC) — to produce a synergistic increase in the capabilities of the alloy with the goal of achieving properties greater than either of the methods could achieve alone. The anticipated advantages of the alloy are higher strength at temperatures up to 700 °C, improved creep strength, and significantly higher LCF lives relative to GRCop-84. The thermal expansion, thermal conductivity, and processing of the alloy are anticipated to remain largely unchanged relative to GRCop-84.

This work was done by David L. Ellis of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18136-1.

Microgravity Storage Vessels and Conveying-Line Feeders for Cohesive Regolith

This design may provide a reliable, robust method for filling pharmaceutical capsules with fine, dry powders.

John H. Glenn Research Center, Cleveland, Ohio

Under microgravity, the usual methods of placing granular solids into, or extracting them from, containers or storage vessels will not function. Alternative methods are required to provide a motive force to move the material. New configurations for microgravity regolith storage vessels that do not resemble terrestrial silos, hoppers, or tanks are proposed. The microgravity-compatible bulk-material storage vessels and exit-feed configurations are designed to reliably empty and feed cohesive material to transfer vessels or conveying ducts or lines without gravity. A controllable motive force drives the cohesive material to the exit opening(s), and provides a reliable means to empty storage vessels and/or to feed microgravity conveying lines. The proposed designs will function equally well in vacuum, or inside of pressurized enclosures.

Typical terrestrial granular solids handling and storage equipment will not function under microgravity, since almost all such equipment relies on gravity to at least move material to an exit location or to place it in the bottom of a container. Under microgravity, there effectively are no directions of up or down, and in order to effect movement of material, some other motive force must be applied to the material. The proposed storage vessels utilize dynamic centrifugal force to effect movement of regolith whenever material needs to be removed from the storage vessel. During simple storage, no dynamic motion or forces are required. The rotation rate during emptying can be controlled to ensure that material will move to the desired exit opening, even if the material is highly cohesive, or has acquired an electrostatic charge.

The general concept of this Swirl Action Utilized for Centrifugal Ejection of Regolith (SAUCER) microgravity storage unit/dynamic feeder is to have an effective slot-hopper (based on the converging angles of the top and bottom conical section of the vessel) with an exit slot around the entire periphery of the SAUCER. The basic shape of such a unit is like two Chinese straw hats (douli) — one upside down, on the bottom, and another on top; or two wok-pans, one upright on the bottom and another inverted on top, with a small gap between the upright and inverted pans or hats (around the periphery). A stationary outer ring, much like an unmounted bicycle tire, surrounds the gap between the two coaxial, nearly conical pieces, forming the top and bottom of the unit.

When the entire unit is spun around its axis, centrifugal forces will exceed the cohesive arch strength of the regolith inside (at some rotational speed), and some material will be ejected through the peripheral slot into the surrounding stationary ring. Multiple small brushes or blades will sweep the extruded material around inside the enclosing stationary ring (tire). A circular hole in the outer ring allows the swirling material to pass through the outer ring wall and into an attached screw conveyor or other unit. Because the opening in the outer ring is circular, there is no preferred orientation for an attached screw conveyor, other than that it would work best if its axis lies in a plane tangent to the outer circumference of the ring. The ring and screw conveyor remain in a fixed orientation, while the top and bottom cones of the SAUCER are connected together (with a gap between them) and rotate about their common axis to produce the centrifugal force, enabling the material inside the SAUCER to be ejected through the outer slot or gap into the dispensing ring. The screw conveyor picks up the material swept through the hole in the outer ring.

Without an externally supplied motive force, a cohesive granular solid will not move under microgravity, but will remain in an open container, independent of the container's orientation, until an external force causes the material to move. The controllable centrifugal force of the proposed SAUCER design provides a rational solution for storage and subsequent emptying of vessels containing cohesive granular solids under microgravity or low-gravity conditions.

This work was done by Otis R. Walton and Hubert J. Vollmer of Grainflow Dynamics, Inc. for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19016-1.