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 un-obtainable. 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.

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**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/m²), 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% Cr₂Nb 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 Cr₂Nb precipitates (GRCop-84), and precipitation strengthening by Cu-Zr (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.

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**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 reli-

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ably empty and feed cohesive material to
transfer vessels or conveying ducts or
lines without gravity. A controllable mo-
tive force drives the cohesive material to
the exit opening(s), and provides a reli-
able means to empty storage vessels
and/or to feed microgravity conveying
lines. The proposed designs will func-
tion equally well in vacuum, or inside of
pressurized enclosures.

Typical terrestrial granular solids han-
dling and storage equipment will not
function under microgravity, since al-
most all such equipment relies on grav-
ity to at least move material to an exit lo-
cation or to place it in the bottom of a
container. Under microgravity, there ef-
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 de-
sired exit opening, even if the material is
highly cohesive, or has acquired an elec-
 trostatic charge.

The general concept of this Swirl Ac-
tion Utilized for Centrifugal Ejection of
Regolith (SAUCER) microgravity stor-
age unit/dynamic feeder is to have an
effective slot-hopper (based on the con-
verging 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 bot-
tom, 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 un-
mounted 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 in-
side (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 mate-
rail around inside the enclosing station-
ary 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 ori-
entation 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 ori-
tentation, 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 re-
main 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 pro-
vides a rational solution for storage and
subsequent emptying of vessels contain-
ing cohesive granular solids under mi-
icrogravity or low-gravity conditions.

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

Inquiries concerning rights for the com-
cercial use of this invention should be addressed to
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