# Phase 2 Project Summary

**Firm: Physical Sciences Inc.**
**Contract Number: NNX10CA46C**
**Project Title: High Performing, Low Temperature Operating, Long Lifetime Aerospace Lubricants**

**Identification and Significance of Innovation:** (Limit 200 words or 2,000 characters whichever is less)

Future success of long-duration, planetary space exploration requires lubricants that can perform effectively over extended lifetimes with minimal or no maintenance in aerospace systems. These systems include rovers and machinery used in constructing the lunar habitat, and bearings in gyroscopes on board satellites whose failure is a leading cause of spacecraft malfunction. Lubricants that are intended for space-use must have a low vapor pressure, be chemically stable, function over a wide temperature range, exhibit low friction coefficients, produce small wear effects, and limit corrosion processes.

Ionic liquids (ILs) show promise for aerospace lubricant applications since they can possess these favorable attributes. Specifically, ILs have been evaluated as additives in various lubricant base fluids. In multiple examples, both the coefficient of friction and wear effects of the formulations were lower than that of the base fluid. However, new IL/base fluid formulations with appropriate thermal, dispersion, corrosion, and tribological characteristics are needed for space applications.

**Technical Objectives and Work Plan:** (Limit 200 words or 2,000 characters whichever is less)

The specific objectives were as follows: 1) Synthesize new ionic liquid lubricants and characterize their purity (>98%) 2) Demonstrate vapor pressures < $10^{-7}$ torr at 25$^{o}$C 3) Show thermal stability up to 250$^{o}$C 4) Demonstrate no additional corrosion of steel substrates when submerged in base fluids which contain an IL additive, relative to the base fluid 5) Show a 20% viscosity decrease (-70$^{o}$C to +60$^{o}$C) of base fluids upon formulation with an IL 6) Demonstrate 20% lower friction coefficients and wear effects of base fluids upon formulation with an IL 7) Scale a scale-up 4 ionic liquids to ~ 25 g each 8) Evaluate performance of a formulation in a NASA test bed.

The work plan was as follows: 1) Synthesize and characterize new ionic liquids. 2) Demonstrate their purity by $^{1}$H NMR, $^{13}$C NMR, and elemental analysis. 3) Measure vapor pressure of each pure ionic liquid. Evaluate thermal decomposition temperatures by DSC and TGA of each ionic liquid. 4) Perform corrosion analysis of each formulation. Image steel substrates by SEM and EDAX. 5) Measure temperature-dependent viscosities of additives and formulations. 6) Perform tribological analysis of formulations 7) Perform scale-up. 8) Evaluate a novel formulation in a NASA test bed.

**Technical Accomplishments:** (Limit 200 words or 2,000 characters whichever is less)

Several technical accomplishments were reached on this program. Specifically, 6 new ionic liquids were synthesized and characterized. Their vapor pressures were shown to be < $10^{-7}$ Torr at 25$^{o}$C. Thermal stability of the ionic liquids up to 250$^{o}$C was demonstrated. The ionic liquids had no measurable influence upon viscosity upon addition to base fluids. The ionic liquids had no measurable influence upon corrosion at steel substrates upon addition to base fluids. In general, 13% - 34 % lower COFs, and 30 % - 80 % higher OK load of base fluids upon addition of the ionic liquids was shown. Each ionic liquid was scaled to ~ 1 - 1.5 g, and delivered to NASA.

**NASA Application(s):** (Limit 100 words or 1,000 characters whichever is less)

The proposed lubricants and formulations will have direct applications to NASA aerospace systems that require minimal/no maintenance over extended periods of time. These systems include rovers and machinery used in constructing the lunar habitat. The compounds will provide lower volatility, decreased wear effects, and better tribological characteristics than those of standard liquid lubricants that are currently used, particularly at lower temperatures.

**Non-NASA Commercial Application(s):** (Limit 200 words or 2,000 characters whichever is less)

The proposed lubricants and formulations have applications in terrestrial machinery. They will substantially increase performance, and reduce maintenance costs and frequencies of industrial transportation and construction systems. The compounds will also be valuable in gyroscope bearings on board satellites.

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