I. INTRODUCTION

The periodic, scheduled, maintenance of commercial jet airplanes, which is carried out by all airlines worldwide, is a critical task that is not taken lightly. All operating parts of the airplane (both mechanical and electrical/electronic) are taken apart and examined for signs of fatigue wear. Those parts that have reached their pre-determined use life, are replaced and the parts that have not attained their useful end point, are examined and put back into use, if no signs of fatigue are noticed.

For reasons of economy (less fuel used during take off), most of the metal components on the airplanes are manufactured from light weight alloys of aluminum or titanium. Provided these parts are not painted, the removal of any dirt or grease on the aluminum or titanium surface, so that inspection can be carried out, is fairly easy. The cleaning job can be accomplished with either solvents or water based products, depending on the type of grease being removed.

However, there are some critical parts of the aircraft that contain some carbon steel components, and the processes used to clean parts such as this cannot have water involved in either the cleaning or rinse cycles. The minimization of the potential for these parts to rust is strictly maintained.

A series of parts that does contain carbon steel components is the collection of the various size ball bearing assemblies, which are part of the mechanism for lowering and raising the landing gear on the aircraft. These units, like all other components on the airplane, are regularly inspected for signs of wear. Before the inspection can be carried out, the bearings have to be cleaned. During use, the bearings require a thick grease as a lubricant. Over time, this lubricant breaks down to form the black carbon filled "used grease" that all are familiar with.

Typically, this grease is removed with a halogenated solvent of some type using a vapor degreasing process (no water involved at all). Some of the solvents used to do the degreasing job are ozone depleting agents (Freon® and 1,1,1-Trichlorethane). Other solvents that are used for grease removal are Trichloroethylene or Perchloroethylene.

The need, for alternative solvent based systems to replace these critical solvent based processes, has to be met. This report outlines some experimental work defining potential replacement technology. For more information contact:

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II. EXPERIMENTAL WORK

A) Definition of Cleaning Job

*Parts cleaned:* Aircraft ball bearing assemblies approximately 4.5 inches in diameter. Bearings were part of land gear system. Bearings manufactured by the Timken Co. Canton, Ohio

*Parts obtained from:* A maintenance center of a major United States based airline.

*Soil removed:* Baked on Aeroshell® Grease 5. A product of the Shell Oil Company

The cleaning process that has to be replaced, is a vapor degreasing process involving Freon® as the cleaning solvent. The technology involves the immersing of the bearings into an ultra sonic bath filled with the solvent. The parts are tumbled during the immersion process to insure that all the grease filler particles are removed from inside the bearing. This immersion cleaning step is followed by a vapor phase rinse of the bearings. Total Cycle Time of the process is 12 - 15 minutes.

B) NMP Based Cleaning Process

Most oils (light, medium, and heavy viscosities) have some degree of solubility in NMP at both room temperature and elevated temperatures.

This is not true for the heavy greases. These compounds have almost no solubility in NMP at room temperature and very minimal solubility even at 68° - 70°C. The NMP has to be formulated with other ingredients that will allow for greater grease solubility in the resulting solution. Put forth below, is such a formulation:

**GREASE REMOVAL FORMULATION**

<table>
<thead>
<tr>
<th>% by weight</th>
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<tbody>
<tr>
<td>NMP</td>
</tr>
<tr>
<td>Dowanol® TPM</td>
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<tr>
<td>LOPS</td>
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Dowanol® TPM (Tripropylene Glycol mono methyl ether) is a product of the Dow Chemical Company.

LOPS (Low Odor Paraffinic Solvent) is a product of the Exxon Company.

*Cleaning Cycle:*

1. The above Grease Removal Formulation was compounded (approx. 1.5 gallons), and a sufficient amount was added to a one gallon lab bench ultrasonic bath.

2. The temperature of the bath was maintained at 63 ± 3°C.

3. A bearing was immersed into the bath. Initially the ultrasonics were turned off. This allows the formulation to begin softening the grease and solvating the light paraffin components. This initial dwell time is 5 minutes. This time span also allows the bearings to get up to the operating temperature of the bath.

4. To simulate the tumbling action which is a necessary part of either the Freon® cleaning system or this replacement system, throughout the cleaning cycle the bearing is tapped into the sides of the bath walls.
What happens to the grease once it enters the NMP cleaning solution?

The NMP solution begins to become black in appearance, while agitation is applied. Once the motion of the bath (tumbling, ultrasonics) is stopped, the burnt carbon black producing the color falls to the bottom of the bath.

As the bath is allowed to cool down, some of the fillers settle to the bottom of the bath, and the longer chain paraffins, which are "semi solid" at room temperature float to the top layer of the bath.

The lighter distilled cuts, from the grease, remain soluble in the NMP solution. Once the solution becomes saturated with these lighter distillates (which may be approx. 3% of the bath weight) the light distillates will separate out of the solution once it cools down to room temperature.

The fillers and carbon black that settle out to the bottom of the bath is particulate matter, and can be filtered out of the solution with an in line filtering pack. The light distillates and "semi solid" paraffins that float to the surface, at room temperature and can be skimmed off.

IV. SAFETY CONSIDERATIONS

Unlike the halogenated solvents currently used to remove grease from bearing assemblies, NMP does have a flash point (196°/91°C). Be sure that all pertinent codes regulating the use of combustible solvents in (and storage near) dip tanks, are adhered to. Along with any state or municipal codes, the following codes should be reviewed:

OSHA: Codes 1910.106 and 1910.108
NFPA: No. 30
NEC CODE: Article 500

NMP is a solvent, and like most solvents, it will de-fat/de-oil the skin. When using NMP, make sure that proper NMP resistant Butyl Rubber gloves are worn. Also, as with all solvents, goggles should be worn to protect the eyes from accidental splashes.
After the 5 minutes initial dwell time, the ultra sonics are turned on. This cycle is for 20 minutes.*

The final step in the cleaning cycle is a 5 minute dwell time in the bath with the ultra sonics turned off. The simulation of the tumbling action is carried out during the step.

**Rinse Cycle**

Immediately following removal from the ultra sonic bath, the bearing is immersed into an agitated bath of hot (63°C) NMP. Since both Dowanol® TPM and LOPS, are soluble in NMP, the trace amount of drag out solvent, left on the bearing from the cleaning bath, is easily removed by the NMP rinse bath. Dwell time in the rinse bath is 2 minutes.

**Drying Cycle**

For this test, the bearings were removed from the rinse bath, and after the drag out solvent was shaken off, were placed into a hot (63°C) forced air oven for 15 minutes.

An alternative method would be to remove the bearings from the rinse bath, and place them into an exhaust hood. Both the parts and the NMP are at 63°C. At this temperature the surface tension of NMP is in the mid 20's dynes/cm. The NMP is in a very thin film, and evaporates relatively quickly from the surface of the bearing.

### NMP BASED GREASE REMOVAL PROCESS OUTLINE:

3 step process

1. **Clean**: Ultrasonic bath; tumble the parts; cleaning fluid temperature 63°C; dwell time in bath 30 minutes; formulated NMP cleaning fluid

2. **Rinse**: Agitated bath; tumble the parts; rinse fluid temperature 63°C; dwell time in rinse bath 2 minutes; 100% NMP rinse

3. **Dry**: Either forced hot air oven dry (63° - 70°C) or open air dry in exhaust hood

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**III. RESULTS AND COMMENTS**

After the bearings were dried, they were returned to the airline’s maintenance facility for inspection. A total of 8 bearings were cleaned in the manner outlined above.

All 8 bearings passed the airlines inspection for cleanliness and all 8 bearings were rust free.

Arrangements have been made to carry out a pilot trial in a larger ultrasonic unit capable of handling a whole basket of Bearings. Also, the manufacturer of the vapor degreaser in the airline maintenance facility (set up for Freon® use), has been contacted to see what will be required to convert the unit into an immersion tank for cleaning with an NMP system.

* * The cycle listed here is for a heavy build up of grease. An alternative cycle that works just as well has the ultrasonics turned on for the entire 30 minute cycle, and tumbling action during the initial 5 minutes and final 5 minutes of the cycle.

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Appendix A:

It had been noticed, in degreasing work done early on with 100% NMP, that as the NMP bath picked up a few % of bath weight of the hydrocarbon that was being cleaned, the ease of removal of the soil from the metal surface increased. This makes sense, as "like dissolves like". The soil sees more of itself in the NMP, and has a greater affinity for the soil/NMP blend, also, the surface tension of the blend is usually less than the surface tension of straight NMP, allowing for easier replacement of soil on the metal surface.

With this knowledge in mind, the initial hydrocarbon-NMP blends were formulated for heavy grease removal. The NMP is essentially "primed" with the hydrocarbon to facilitate easier, faster grease removal.

Since this initial work, a more "natural" approach to getting the "hydrocarbon prime" into the NMP solution, has developed.

Due to the unsaturated components in the natural oils (corn oil, sunflower oil, soybean oil, olive oil, peanut oil... these sources of hydrocarbon, are readily soluble in NMP.

Most natural oils have extremely high solubilities in NMP, and blends as high as 50/50 (% by weight) can be mixed at room temperature. With this knowledge in mind it was decided that NMP natural oil blends would make very good heavy grease removers.

Following the same process as outlined in this report, keeping everything constant except for the NMP based cleaning solution chemical make up, bearing assemblies supplied by the same airline maintenance facility were successfully cleaned. The make up of the NMP cleaning bath was:

<table>
<thead>
<tr>
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<th>(% by weight)</th>
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<tbody>
<tr>
<td>NMP</td>
<td>65.0</td>
</tr>
<tr>
<td>Peanut Oil*</td>
<td>35.0</td>
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* Any one of the natural oils probably would have worked, it just happened that there was some peanut oil in the lab.

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