ERDC/CRREL TR-11-7

Cold Regions Research and
Engineering Laboratory

US Army Corps
of Engineers®
Engineer Research and
Development Center

# Feasibility of Overland Traverse to Re-Supply Summit Camp

## Fleet Configuration and Economic Analysis

James H. Lever, and Jason C. Weale

March 2011

ERDC/CRREL TR-11-7
March 2011

# Feasibility of Overland Traverse to Re-Supply Summit Camp

## Fleet Configuration and Economic Analysis

James H. Lever, and Jason C. Weale

*Cold Regions Research and Engineering Laboratory*
*U.S. Army Engineer Research and Development Center*
*72 Lyme Road*
*Hanover, NH 03755*

Final report

Prepared for National Science Foundation
Office of Polar Programs,
Division of Arctic Sciences
Washington, DC 20314-1000

**Abstract:** The feasibility of re-supplying Summit Camp on the Greenland ice cap from Thule AFB via a 1200-mile (round trip) overland traverse was examined. The assessment focused on the delivery capabilities of tractor fleets consisting of 2–4 prime movers and their economics compared with re-supply by LC130 aircraft. Initiating a Thule-Summit traverse using a three-tractor fleet conducting one round trip per season can deliver most of the fuel (37,000 gal.) and durable cargo (160,000 lb) needed annually at Summit. A two-tractor fleet conducting two round trips per season would offset ~ 21 LC130 flights (45,000 gal. fuel, 160,000 lb cargo). The delivery capacity of a four-tractor fleet (47,000 gal. fuel, 240,000 lb cargo) exceeds the present needs at Summit but could service cargo needs for U.S. and international science camps operating along or near the traverse route and it would offset 25 LC130 flights. These results indicate that an overland traverse to re-supply Summit Camp is feasible on delivery efficiency and economic grounds. It would also buffer the program against increases in fuel and flight costs for LC130s. Additional work is needed to prove a safe route onto the ice cap from Thule AFB and to develop an efficient cargo sled based on experience with fuel bladder sleds. Preliminary work suggests that solutions for these issues are straightforward.

# Table of Contents

# List of Figures and Tables

## Figures

## Tables

# Preface

This study was conducted for the National Science Foundation–Office of Polar Programs, Division of Arctic Sciences (NSF-OPP ARC) under Project 07-02, *Greenland Traverse Feasibility Study and Planning*.

The work was performed by Dr. James H. Lever and Jason C. Weale of the Force Projection and Sustainment Branch (CEERD-RR-H), Research and Engineering Division (CEERD-RR), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL).

The report was prepared under the general supervision of James Buska, Chief, Force Projection and Sustainment Branch; Dr. Justin B. Berman, Chief, Research and Engineering Division; Dr. Lance D. Hansen, Deputy Director; and Dr. Robert E. Davis, Director, CRREL.

Colonel Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was ERDC Director.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| gallons (U.S. liquid) | $3.785412 \times 10^{-3}$ | cubic meters |
| horsepower (550 foot-pounds force per second) | 745.6999 | watts |
| miles (U.S. statute) | 1,609.347 | meters |
| pounds (mass) | 0.45359237 | kilograms |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |

# 1 Executive Summary

At the request of the National Science Foundation–Office of Polar Programs, Division of Arctic Sciences (NSF-OPP ARC) we examined the feasibility of re-supplying Summit Camp on the Greenland ice cap from Thule AFB via a 1200-mile (round trip) overland traverse. Our assessment focused on delivery capabilities tractor fleets consisting of two to four prime movers and their economics compared with re-supply by LC130 aircraft. Data for these analyses derive from our experience with the successful South Pole Traverse, which covers similar distances and snow conditions in Antarctica. Annual re-supply needs at Summit are approximately 40,000 gal. fuel, 200,000 lb non-science cargo and 120,000 lb retro-cargo. For this analysis, we assume that route development posses no serious challenges. All fleet scenarios investigated easily return with the required retro-cargo and could deliver cargo too large to fit in an LC130.

We recommend initiating a Thule–Summit traverse using a three-tractor fleet. A three-tractor fleet conducting one round trip per season can deliver most of the fuel (37,000 gal.) and durable cargo (160,000 lb) needed annually at Summit. This traverse scenario would annually offset 18.5 LC130 flights from Kangerlussuaq at a net savings of about $380,000/yr on an initial investment of about $2.2 million. Importantly, the traverse would consume 23% of the fuel, contribute 0.3% of the overall air emissions, and 0.04% of the near-Summit air emissions compared with aircraft to deliver the same fuel and cargo.

A two-tractor fleet could be a spin-up option, delivering 39,000 gal. of fuel (about 12 LC130 flights). It would reduce initial investment by about $0.4 million and retain impressive fuel and emission reductions, albeit with lower net annual savings ($150,000/yr). Interestingly, a two-tractor fleet conducting two round trips per season would offset about 21 LC130 flights (45,000 gal. fuel, 160,000 lb cargo). However, a tractor breakdown en route has high impact on a two-tractor fleet, and we would not recommend using it except as a short-term option to spread out fleet acquisition.

The delivery capacity of a four-tractor fleet (47,000 gal. fuel, 240,000 lb cargo) exceeds the present needs at Summit but could service cargo needs for U.S. and international science camps operating along or near the traverse route. With $0.5 million additional investment compared with the three-tractor fleet, it would offset 25 LC130 flights at net annual savings of $580,000 and further reduce fuel consumption and emissions compared with LC130 flights.

These results indicate that an overland traverse to re-supply Summit Camp is feasible on delivery efficiency and economic grounds. It would also buffer the program against increases in fuel and flight costs for LC130s. Additional work is needed to prove a safe route onto the ice cap from Thule AFB and to develop an efficient cargo sled based on experience with fuel bladder sleds. Preliminary work suggests that solutions for these issues are straightforward. We therefore expect that an overland traverse will provide large logistic, economic and environmental benefits as an alternative to aircraft re-supply for Summit Camp.

Note: This work was completed in December 2007 prior to the inaugural Greenland Inland Traverse conducted in spring–summer 2008.

# 2 Introduction

The National Science Foundation, Office of Polar Programs (NSF/OPP) maintains a year-round research station at Summit Camp on the Greenland ice cap at 10,500 ft elevation (Fig.1). Re-supply of fuel and cargo for Summit is currently by ski-equipped LC130 (Hercules) aircraft, which take off on wheels from Kangerlussuaq and land on a skiway at Summit. The aircraft averaged 30 flights per season over the three April–August summer seasons 2005–07.

NSF/OPP is considering using an over-land traverse to re-supply Summit Camp from Thule AFB, a distance of about 600 miles. This interest stems in part from the success of the South Pole Traverse (SPT), which developed equipment and techniques to re-supply South Pole Station from McMurdo Station in Antarctica. About 600 miles of the 1000-mile SPT route is over the Ross Ice Shelf near sea level; after ascending the Leverett Glacier, the route covers 300 miles across the Polar Plateau at 2200–2900 m elevation. The SPT fleet consists of heavy-duty agricultural tractors pulling a mix of support, fuel, and cargo sleds (Fig. 2). Over four field seasons, the SPT team has significantly improved the performance of these sleds, especially the fuel sleds, and consequently has greatly increased the potential delivery efficiency of the fleet (Lever et al. 2004, 2006; Weale and Lever 2008). Because the snow conditions and elevations are similar, we expect that tractors and sleds employed on the SPT would perform well in Greenland. This allows us to use extensive mobility and cost data from the SPT to assess the feasibility of a Thule–Summit traverse. Specifically, our objectives here are to compare the performance and cost of traverse fleets composed of two to four tractors with the performance and cost of LC130 aircraft to deliver the same cargo. In addition, an over-snow traverse provides flexibility to deliver outsized and overweight cargo without the dimensional and weight constraints of cargo aircraft. This information will help NSF-OPP Division of Arctic Sciences (ARC) decide whether or not to implement a traverse as an alternative to aircraft re-supply of Summit Camp.

Figure 1. Greenland showing approximate locations of Summit Camp, Kangerlussuaq and points of interest along a traverse route from Thule AFB to Summit.

Figure 2. Example tractors and sleds used on the South Pole Traverse (top to bottom): Case STX450 tractor pulling four fuel tanks in 2 × 2 configuration; living and energy modules for fleet support; newly developed fuel-bladder sleds; cargo sleds.

# 3 Summit Camp Transportation Requirements and LC130 Status Quo

The New York Air National Guard flies all LC130 re-supply flights to Summit Camp. They provided summaries of fuel, cargo and passengers delivered to Summit for each flight conducted during the 2002–2007 seasons. We analyzed the data for the last three seasons (2005–07) to estimate transportation requirements for this study (Table 1). The ANG uses a density of 6.65 lb/gal. to convert fuel volume to weight.

Table 1. Summary of LC130 re-supply flights to Summit Camp for 2005–07 seasons and derived fuel, durable cargo, and durable retro-cargo goals for a traverse.

| Season | Total Flights | Fuel Delivered (gal.) | Cargo Delivered (lb) | Passengers In | Retro-Cargo (lb) | Payload Delivered per Flight (lb) |
|---|---|---|---|---|---|---|
| 2007 | 22 | 34,606 | 186,965 | 185 | 129,010 | 21,313 |
| 2006 | 31 | 45,096 | 286,836 | 122 | 278,551 | 20,696 |
| 2005 | 39 | 53,929 | 490,975 | 157 | 74,050 | 22,912 |
| *average 2005–07* | *31* | *44,544* | *321,592* | *155* | *160,537* | *21,640* |
| traverse goals | | 40,000 | 200,000 | | 120,000 | |

Fuel and cargo delivered to Summit and retro-cargo returned all varied substantially over the three seasons, with a trend towards decreasing deliveries of fuel and cargo. These quantities will continue to vary with science activity, camp redevelopment, and the introduction of alternative energy sources.

A traverse should be able to deliver essentially all fuel needed at Summit. We assume that the long-term fuel-delivery need will be about 40,000 gal. per year, slightly less than the 2005–07 average. We also assume that passengers, science cargo, and perishable food, as time-sensitive items, will continue to reach Summit by aircraft. We thus approximate the durable-cargo delivery goal as 200,000 lb per year or about $^2/_3$ of the average cargo delivered 2005–07. Similarly, science retro-cargo is time-sensitive, so we assume that 120,000 lb per season, or ¾ of the 2005–07 average, approximates the durable retro-cargo goal for a traverse. Note that a traverse could deliver over-size cargo that would not fit inside an LC130 (e.g., prefabricated camp buildings), providing design flexibility and reducing fabrication costs beyond simply offsetting LC130 flights.

The 2005–07 LC130 total payload weight averaged about 22,000 lb per flight. Fuel-only flights averaged slightly less at 20,000 lb (3000 gal.). Nevertheless, we will use 22,000 lb/flight as the payload capability of an LC130 flight to Summit for both fuel and cargo.

The ANG also provided data on fuel consumption for flights to Summit. Table 2 provides the breakdown.

Table 2. Fuel consumption for Kanger–Summit–Kanger flights.

| Flight Segment | Fuel Consumption (lb) |
|---|---|
| Kanger–Summit (2 hr) | 10,000 |
| taxi in | 250 |
| cargo transfer (0.75 hr) | 1500 |
| taxi out | 250 |
| takeoff slide | 1300 |
| Summit–Kanger (2 hr) | 10,000 |
| *Total* | *23,300* |

No information was provided on fuel consumed during takeoff at Kangerlussuaq, so we may estimate that one round trip consumes about 24,000 lb of fuel (3600 gal.). The ANG data did not include number of takeoff slides needed at Summit or whether jet-assisted takeoff bottles (JATO) were needed. It did note that six flights attempted in 2005 were aborted over Summit, presumable owing to poor visibility. Nevertheless, we use 24,000 lb as a conservative estimate of the fuel consumption for each LC130 re-supply flight to Summit. This figure indicates that LC130 flights consume 1.09 pounds of fuel for every pound of fuel or cargo delivered to Summit (24,000-lb-consumed/22,000-lb-delivered).

Currently, the ANG charges NSF $6100 per hour of engine-on time for LC130 flights. Each re-supply flight includes 4 hr flying time and about 1 hr at Summit. If we assume that 0.5 hr is needed at Kangerlussuaq, each re-supply flight requires about 5.5 engine-on hr at a cost of $34,000.

# 4 Traverse Fleet Mobility Data

The South Pole Traverse offers a source of mobility data for tractors and sleds capable of long-distance, heavy traverse over snow (Lever et al. 2004, 2006; Weale and Lever 2008). We select here the most promising SPT tractors and sleds to configure fleets for Summit re-supply feasibility assessment. SPT experience indicates that the required towing force for sled trains should be the mean resistance plus 3 standard deviations to avoid frequent immobilization.

The STP included a Case STX450 “Quadtrac” tractor in its initial fleet (2003–04) and added a second one with a plowing blade for the 2004–05 season. In part based on our recommendations, the SPT added two Case STX530 tractors to capitalize on their higher engine power (530 hp vs. 450 hp) and fitted them with dual auxiliary 300-gal. rear fuel tanks and slightly wider blades (Fig. 3). Data from Case indicate that the larger engines are more fuel efficient ([lb-fuel/hr]/hp) and should be as reliable as the smaller engines. Data from November 2007 CRREL mobility tests conducted in Antarctica indicate that new Case STX530 tractors have higher drawbar pull (25,800 lb), consistent with their higher weight. Fuel consumption should be similar to the STX430, which scales with required towing force (2.35 ton-mile/gal. at high drawbar).

Figure 3. Case STX530 with plowing blade and dual auxiliary 300-gal. rear fuel tanks.

The SPT has used steel 3000-gal. fuel tanks each year to haul fuel for its fleet. We reduced the towing resistance of these tank sleds by placing their skis outside of tractor ruts, lowering their ground pressure (larger skis), and altering the ski noses to reduce plowing. A STX530 tractor towed six of these full fuel tanks during November 2007 mobility tests. Measured towing resistance was 3700 lb per tank (mean resistance plus 3σ), suggesting that the STX530 could pull seven full tanks over snow typical of the SPT route. To reduce towing resistance further, CRREL designed, and the SPT deployed in the 2005–06 season, a fuel sled consisting of a fuel bladder strapped to a sheet of low-friction ultra-high molecular weight (UHMW) polyethylene (Fig. 2). This sled performed very well, and for 2007–08, the fleet includes twelve 3000-gal. fuel bladders strapped in pairs to 8-ft-wide × 64-ft-long UHMW sleds (Fig. 4). The STX530 pulled all twelve full bladders with less resistance than the six tank sleds. Measured towing resistance was 1500 lb per bladder, suggesting that the STX530 could pull 17 full bladders over snow typical of the SPT route.

Figure 4. SPT bladder sleds assembled for the 2007-08 season. Each sled consists of two 3,000-gal. bladders strapped to a welded sheet of UHMW. Here, four sleds are laced together to form a group of eight bladders for towing behind a single tractor using a spreader bar.

The current SPT steel cargo sleds (Fig. 2) have high tare weights and resistance coefficients and thus are much less efficient than either the tank or bladder sleds. We expect to develop for the SPT a flexible cargo sled using technology similar to the bladder sleds (i.e., a flexible interface between cargo pallets and a UHMW sheet). Such a cargo sled will likely have higher tare weight and a slightly higher resistance coefficient than the bladder sleds, so that the towing resistance for when carrying 20,000 lb of payload should be about 2100 lb on the SPT route.

The SPT fleet-support sleds consist of a living module accommodating eight persons, an energy module with dual generators, and two cargo sleds carrying food and supplies (Fig. 2). The Thule–Summit traverse will need similar fleet-support sleds. We assume here that the traverse will require a maximum of four persons and scale the fleet-support sleds accordingly.

The traverse scenarios developed here consist of Case STX530 tractors (or equivalent), 3000-gal. bladder sleds, a single 3000-gal. tank sled for daily fuel transfers, 20,000-lb flexible cargo sleds, and fleet-support sleds for four-persons, with designs and mobility performance based on SPT parameters. However, the trafficability of snow over the Greenland ice cap from Thule to Summit is unknown as yet; snow could be weaker owing to higher accumulation rates compared with the SPT route. To be conservative, we assume here that tractor drawbar pull will be 20% lower (21,000 lb), fuel efficiency will be 20% lower (1.9 ton-mi/gal.) and sled towing resistance will be 20% higher than comparable SPT values. Table 3 summaries the resulting sled performance parameters.

Table 3. Sled weights and required towing resistance (mean plus 3σ) for Thule-Summit traverse.

| Sleds | Weight (lb) | Towing Resistance (lb) |
|---|---|---|
| Living & Energy Modules | 50,000 | 6,000 |
| Supplies (food and parts) | 32,000 | 3,800 |
| bladder sled-full (3000 gal.) | 22,000 | 1,800 |
| bladder sled-empty | 1,850 | 100 |
| existing tank-empty | 12,410 | 1,500 |
| existing tank-full | 33,060 | 4,000 |
| cargo sleds—20,000 lb | 23,000 | 2,500 |
| cargo sleds—empty | 3000 | 300 |

# 5 Thule-Summit Traverse Scenarios

A traverse route from Thule–Summit, passing through NEEM drill camp, would be 600 miles long. We assume that access to the ice cap near Thule is feasible and no insurmountable terrain obstacles (crevasses, large sastrugi) exist along the route. Base on SPT experience, the fully loaded outbound fleet should be able to cover 50 miles per day and the returning lightly loaded fleet should cover 80 miles per day. This results in travel times of 12 days outbound and 8 days returning, so that one round trip including cargo transfer at Summit should take less than 4 weeks.

We investigated the feasibility of traverse fleets consisting of two–four tractors conducting one round trip per year and a two-tractor fleet conducting two round trips per year. All sled trains are configured so that the total resistance is just below de-rated drawbar capacity of the tractor. For simplicity and to allow future expansion, we assume that all fleets utilize a four-person living module and associated support sleds. Also, we assume that the two-tractor fleet would require three persons for safety reasons.

The results indicate that the four-tractor scenario could exceed the Summit delivery goals of 40,000 gal. of fuel and 200,000 lb durable cargo. The three-tractor and two-tractors-twice scenarios nearly meet these goals. All scenarios can meet the goal of returning with 120,000 lb of retro-cargo. We present the three-tractor scenario in some detail and summarize the results for all scenarios.

The three STX530 tractors would be configured in the following trains for the outbound leg:

- Tractor 1—fleet support sleds, one 3000-gal. steel tank, four 3000-gal. bladders
- Tractor 2—twelve 3000-gal. bladders
- Tractor 3—eight 20,000-lb flexible cargo sleds

The fleet would depart Thule with 53,700 gal. of fuel (including full tractor tanks) and 160,000 lb of cargo. It would consume 9900 gal. of fuel during the outbound leg and deliver to Summit 37,000 gal. of fuel and all 160,000 lb of cargo. It would load up with 120,000 lb of retro-cargo, depart Summit with 6800 gal. of fuel, consume 5200 gal. during the return leg, and arrive back at Thule with a fuel reserve of 1600 gal.

Under this scenario, the traverse would offset 18.5 LC130 re-supply flights to Summit while consuming only 23% of the fuel needed to deliver the same total payload (406,000 lb). Table 4 summarizes the performance results for all scenarios analyzed.

Table 4. Performance summary of traverse scenarios analyzed. The delivery goals are 40,000 gal. fuel and 200,000 lb durable cargo to re-supply Summit entirely by traverse. All scenarios return with 120,000 lb of retro-cargo. Note that LC130 flights consume 1.09 lb of fuel per lb of payload delivered to Summit.

| Scenario | Fuel Delivered (gal.) | Cargo Delivered (lb) | Fuel Consumed (gal.) | Fuel Consumed/ Payload Delivered | LC130 Flights Offset | Fuel Consumed (%LC130) | Emissions (%LC130) |
|---|---|---|---|---|---|---|---|
| Four tractors | 47,000 | 240,000 | 18,000 | 0.22 | 25.1 | 20 | 0.27 |
| Three tractors | 37,000 | 160,000 | 15,000 | 0.25 | 18.5 | 23 | 0.30 |
| Two tractors | 39,000 | 0 | 12,000 | 0.31 | 11.8 | 28 | 0.38 |
| Two tractors twice | 45,000 | 160,000 | 21,000 | 0.31 | 20.9 | 28 | 0.38 |

# 6 Air Emissions

To implement surface traverses in Antarctica, NSF/OPP was required to prepare a Comprehensive Environmental Evaluation (CEE) to identify and evaluate potential environmental and operational impacts (NSF 2004). This CEE was subject to the scrutiny and approval by the other member-countries covered by the Antarctic Treaty. The CEE presented several optimized traverse scenarios to re-supply Amundsen-Scott South Pole Station from McMurdo Station. It then estimated the environmental impacts associated with these scenarios and compared them with those by LC130 re-supply flights.

Section 6.3.2 of the CEE presents estimates of cargo transported, fuel usage, and air emissions for SPT scenarios and LC130 re-supply flights. Annual emission for characteristic air pollutants from hydrocarbon fuel combustion were estimated using models developed by the U.S. EPA and included emissions from traverse tractors, generators, heaters, and snowmobiles, and LC130 engines. Table 6-3 of the CEE summaries these results.

The CEE's traverse scenarios, equipment anticipated, distances traveled, and LC130 flight profiles are sufficiently similar to those considered here that we may use SPT normalized emissions (lb/1000-lb fuel consumption) to estimate emissions to re-supply Summit Camp. Table 5 presents the results for the three-tractor traverse scenario for all five combustion byproducts analyzed in the CEE.

Traverse re-supply of Summit Camp offers impressive reductions in air emissions compared with LC130 flights. The main reductions result from much lower emissions per unit fuel consumed. Secondary reductions derive from lower fuel consumption to deliver the same payload to Summit. For simplicity, we also present the average reduction expected for all five pollutants, ignoring differences in environmental impacts from these pollutants. Table 4 presents this same average emission reduction for all traverse scenarios analyzed here.

Table 5. Annual air emissions for traverse scenarios compared with those by LC130 re-supply flights. The first three rows derive from Table 6-3 of the CEE for South Pole re-supply (NSF 2004), normalized by fuel consumed. The last row presents the traverse/LC130 emission ratios to re-supply Summit via the three-tractor scenario.

| | | *Normalized Emissions (lb/1000-lb fuel consumption)* | | | | | |
|---|---|---|---|---|---|---|---|
| Delivery Mode | Fuel Consumed (k-lb) | Sulfur Oxides | Nitrogen Oxides | Carbon Monoxide | Exhaust Hydro-carbons | Particulates | Average Emission Ratio |
| South Pole Traverse | 1318 | 0.083 | 0.045 | 0.017 | 0.002 | 0.004 | |
| LC130 South Pole re-supply | 2109 | 1.42 | 11.22 | 7.54 | 3.36 | 3.09 | |
| SPT/LC130 emission ratio per unit fuel use (%) | | 6 | 0.4 | 0.2 | 0.1 | 0.1 | 1.3 |
| Three-tractor traverse/LC130 emission ratio per unit payload delivered to Summit Camp (%) | | 1.3 | 0.09 | 0.05 | 0.02 | 0.03 | 0.30 |

Note that this analysis also ignores differences in location of the air emissions between traverse and LC130 re-supply profiles. All emission by traverse will be at ground level, while most of the LC130 emissions occur at their flight altitude. These location differences also imply different environmental impacts.

Some concern exists regarding near-surface emissions in the vicinity of Summit Camp because these affect clean air and snow science experiments. About 3300 lb (14%) of the estimated 24,000 lb per LC130 re-supply flight are burned near ground level at Summit (Table 2). This underestimates the impact near Summit because climb-out probably disproportionately burns fuel associated with the 2-hr (10,000-lb) flight back to Kanger. By comparison, a traverse will consume about 1.7% of its total fuel (~ 250 gal. or 1700 lb for a three-tractor fleet) within 10 miles of Summit. However, a three-tractor traverse will offset 18.5 LC130 re-supply flights and will thus consume near Summit only 2.7% of the LC130 fuel needed to deliver the same cargo. Furthermore, on average the traverse emits only 1.3% of the LC130 pollutants per unit fuel consumed. Thus, the three tractor traverse would cause near-Summit air emissions less than 0.04% of that caused by LC130 flights to deliver the same total payload. Note also that a traverse can shut down while at Summit and can approach from the north, away from the clean-air sector south of the camp.

# 7 Economic Analysis

We compare here the costs to re-supply Summit Camp by traverse from Thule with those to re-supply Summit by LC130 from Kangerlussuaq. This requires a number of assumptions, the most important of which is that the costs to ship fuel and durable cargo to Thule are approximately the same as those to Kanger. In fact, LC130 flights from Scotia, NY, currently deliver all durable cargo to Kanger, whereas a ship, currently with excess capacity, can deliver cargo to Thule. Unfortunately, the contract with ANG makes it difficult to break out costs for Scotia–Kanger–Scotia re-supply flights. We expect that these costs are higher than vessel re-supply to Thule. Ignoring this difference ensures that the analysis here is conservative with respect to benefits expected from a Thule–Summit traverse.

The remaining economic assumptions are listed below:

- Discount rate—5% p.a.
- Useful life—10 years for tractors, spare parts, steel sleds; 5 years for bladder sleds and flexible cargo sleds.
- Traverse fuel cost at Thule—$4/gal.
- LC130 fuel cost at Kanger—$4/gal.
- Contingencies—10% on traverse capital costs, 20% on traverse operating costs, 10% on LC130 costs (currently $34,000 per Kanger–Summit–Kanger re-supply flight).

Table 6 lists capital and annual operating costs for the three-tractor traverse and LC130 costs for the 18.5 re-supply flights offset by this traverse. Including annualized capital costs, the three-tractor traverse would save $380,000 per year compared with LC130 re-supply. The net operating savings of $722,000 would pay back the $2.2 million investment in traverse equipment in just over 3 years.

Table 7 summarizes the economic analyses for the other traverse scenarios. All scenarios produce high cost savings. The four-tractor traverse produces the highest net annual savings, assuming that its excess delivery capacity could be used at Summit or elsewhere along the route. The two-tractor-twice scenario produces the shortest payback period owing to its low capital cost.

Table 6. Three-tractor traverse capital and operating costs and LC130 costs to deliver the same payload to Summit (18.5 re-supply flights).

| Traverse Capital Costs | Unit Cost with Contingency | Number | Total Capital Cost | Annualized Capital Cost |
|---|---|---|---|---|
| Case STX 530 | $363,000 | 3 | $1,089,000 | $141,030 |
| spare parts kit | $ 22,000 | 3 | $66,000 | $8547 |
| living/energy module | $330,000 | 1 | $330,000 | $42,737 |
| supply sled | $ 110,000 | 1 | $110,000 | $14,246 |
| tank sled | $ 110,000 | 1 | $110,000 | $14,246 |
| bladder sleds | $27,500 | 16 | $440,000 | $101,629 |
| flexible cargo sleds | $8800 | 8 | $70,400 | $16,261 |
| sub total | | | $2,215,400 | $338,695 |

| Traverse Operating Costs | Annual Cost with Contingency |
|---|---|
| labor (3 @ 3 mo x $60k/yr) | $54,000 |
| maintenance, food, admin | $90,000 |
| fuel | $72,366 |
| Thule space & shop time | $45,000 |
| sub total | $261,366 |
| Total Annualized Traverse | $600,061 |

| LC130 Costs | Annual Cost with Contingency |
|---|---|
| flight costs | $690,285 |
| fuel | $293,089 |
| Total Annual LC130 | $983,374 |
| | |
| Net Annual Savings | $383,313 |
| Payback Period (yr) | 3.1 |

Table 7. Summary of economic analyses for all traverse scenarios.

| Scenario | Capital Cost ($M) | Net Annual Savings ($M) | Payback Period (yr) |
|---|---|---|---|
| Four tractors | 2.7 | 0.58 | 2.8 |
| Three tractors | 2.2 | 0.38 | 3.1 |
| Two tractors | 1.8 | 0.15 | 4.2 |
| Two tractors twice | 1.8 | 0.44 | 2.5 |

Note that a traverse could transport to Summit cargo too large to fit inside an LC130. Larger units would likely reduce U.S. fabricating costs, reduce assembly costs at Summit, and permit construction of more efficient buildings. These benefits would improve the economic performance of all traverse scenarios.

# 8 Discussion and Recommendations

Re-supply of Summit Camp via overland traverse from Thule is attractive on several grounds. The South Pole Traverse has substantially improved the technology to conduct heavy traverses over polar snowfields, and a Greenland traverse would begin with this knowledge base. A Thule –Summit traverse would offset a large fraction of the LC130 re-supply fights for Summit's annual fuel, durable cargo, and retro-cargo needs (40,000 gal., 200,000 lb, 120,000 lb, respectively). Importantly, it would do so with impressive reductions in fuel consumption and air emissions and it would save money compared with LC130 flights. It would help insulate the Arctic program from increases in fuel and flying costs. Furthermore, a traverse would be able to transport cargo too large to fit inside an LC130, provide a robust alternate re-supply system, and re-supply science camps that could develop along the route.

We assessed the delivery capabilities of two–four tractor traverse fleets, their economics compared with re-supply by LC130. Table 8 summaries the overall results. All traverse fleets are feasible on delivery efficiency and economic grounds.

We recommend initiating a Thule–Summit traverse using a three-tractor fleet. A three-tractor fleet conducting one round trip per season can deliver most of the fuel (37,000 gal.) and durable cargo (160,000 lb) needed annually at Summit. This traverse scenario would annually offset 18.5 LC130 flights from Kangerlussuaq at a net savings of about $380,000/yr on an initial investment of about $2.2 million. Importantly, the traverse would consume only 23% of the fuel, contribute 0.3% of the overall air emissions and 0.04% of the near-Summit air emissions compared with aircraft to deliver the same fuel and cargo. The four-person living module could accommodate a scientist or extra crew member and would permit easy expansion of the fleet to four tractors.

A two-tractor fleet could be a spin-up option, delivering 39,000 gal. of fuel (about 12 LC130 flights) and reducing initial investment by about $0.4 million, while retain impressive fuel and emission reductions. Interestingly, running the two-tractor fleet twice in one season offsets 21 LC130 flights (45,000 gal. fuel, 160,000 lb cargo) and has the shortest payback period. However, a tractor breakdown en route, a reasonably likely occurrence given SPT experience, has high impact on a two-tractor fleet. The tractor would essentially require field repair, perhaps necessitating deep-field parts supply by aircraft. Larger fleets have more flexibility to deal with tractor breakdowns. Besides deep-field repair, the remaining tractors can reconfigure loads to tow the disabled tractor to Thule or Summit on lightweight rescue sleds. That is, we would not recommend using a two-tractor fleet except as a short-term option to spread out fleet acquisition over a couple of seasons.

Table 8. Summary of key performance and economic results for Thule-Summit traverse fleets compared with LC130 re-supply flights.

| Scenario | Fuel Delivered (gal.) | Cargo Delivered (lb) | Fuel Consumed (gal.) | Fuel Consumed/Payload Delivered | LC130 offset |
|---|---|---|---|---|---|
| Four tractors | 47,000 | 240,000 | 18,000 | 0.22 | 25.1 |
| Three tractors | 37,000 | 160,000 | 15,000 | 0.25 | 18.5 |
| Two tractors | 39,000 | 0 | 12,000 | 0.31 | 11.8 |
| Two tractors twice | 45,000 | 160,000 | 21,000 | 0.31 | 20.9 |

| Scenario | Fuel Consumed (%LC130) | Emissions (%LC130) | Capital Cost ($M) | Net Annual Savings ($M) | Payback Period (yr) |
|---|---|---|---|---|---|
| Four tractors | 20% | 0.27% | 2.7 | 0.58 | 2.8 |
| Three tractors | 23% | 0.30% | 2.2 | 0.38 | 3.1 |
| Two tractors | 28% | 0.38% | 1.8 | 0.15 | 4.2 |
| Two tractors twice | 28% | 0.38% | 1.8 | 0.44 | 2.5 |

The delivery capacity of a four-tractor fleet (47,000 gal. fuel, 240,000 lb cargo) exceeds the present needs at Summit but could service cargo needs for U.S. and international science camps operating along or near the traverse route. With $0.5 million additional investment compared with the three-tractor fleet, it would offset 25 LC130 flights at net annual savings of $580,000 and further reduce fuel consumption and emissions compared with LC130 flights. Because the three-tractor fleet would utilize four-person support sleds, the fourth tractor could be added easily when delivery needs increased.

Additional work is needed to prove a safe route onto the ice cap from Thule AFB and to develop an efficient cargo sled based on experience with fuel bladder sleds. Preliminary work suggests that solutions for these issues are straightforward. We therefore expect that an overland traverse will provide large logistic, economic and environmental benefits as an alternative to aircraft re-supply for Summit Camp.

# References

Lever, J. H., J. C. Weale, R. G. Alger, and G. L. Blaisdell. 2004. *Mobility of cargo trains during year two of the proof-of-concept South Pole Traverse*. Cold Regions Research and Engineering Laboratory, Hanover, NH: ERDC/CRREL Technical Report TR-04-22.

Lever, J. H., J. C.Weale, R. G. Alger, G. L. Blaisdell and J. H. Wright. 2006. Mobility solutions for the South Pole traverse tractor-sled trains. In *Proceedings of the 10th European Conference of the International Society for Terrain-Vehicle Systems (ISTVS),* Budapest, Hungary (CD-ROM).

NSF. 2004. *Development and implementation of surface traverse capabilities in Antarctica: Comprehensive environmental evaluation*, 30 August 2004, National Science Foundation, Arlington, VA.

Weale, J. C. and J. H. Lever. 2008. Innovations in over-snow cargo transport. *Cold Regions Science and Technology*, 52: 166–176.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

| | | |
|---|---|---|
| **1. REPORT DATE** *(DD-MM-YYYY)*<br>March 2011 | **2. REPORT TYPE** | **3. DATES COVERED** *(From - To)* |

**4. TITLE AND SUBTITLE**

Feasibility of Overland Traverse to Re-Supply Summit Camp

Fleet Configuration and Economic Analysis

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

James H. Lever, and Jason C. Weale

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755

**8. PERFORMING ORGANIZATION REPORT NUMBER**

ERDC/CRREL TR-11-7

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

National Science Foundation
Office of Polar Programs,
Division of Arctic Sciences
Washington, DC 20314-1000

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

The feasibility of re-supplying on the Greenland ice cap from Thule AFB via a 1200-mile (round trip) overland traverse was examined. The assessment focused on the delivery capabilities of tractor fleets consisting of 2–4 prime movers and their economics compared with re-supply by LC130 aircraft. Initiating a Thule-Summit traverse using a three-tractor fleet conducting one round trip per season can deliver most of the fuel (37,000 gal.) and durable cargo (160,000 lb) needed annually at Summit. A two-tractor fleet conducting two round trips per season would offset ~ 21 LC130 flights (45,000 gal. fuel, 160,000 lb cargo). The delivery capacity of a four-tractor fleet (47,000 gal. fuel, 240,000 lb cargo) exceeds the present needs at Summit but could service cargo needs for U.S. and international science camps operating along or near the traverse route and it would offset 25 LC130 flights. These results indicate that an overland traverse to re-supply Summit Camp is feasible on delivery efficiency and economic grounds. It would also buffer the program against increases in fuel and flight costs for LC130s. Additional work is needed to prove a safe route onto the ice cap from Thule AFB and to develop an efficient cargo sled based on experience with fuel bladder sleds. Preliminary work suggests that solutions for these issues are straightforward.

**15. SUBJECT TERMS**

Cargo sleds
Economic efficiency
Environmental quality
Greenland ice cap
Overland traverse vs. LC130 aircraft
Re-supplying Summit Camp
Summit Camp
Tractor fleet

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | | | **19b. TELEPHONE NUMBER** *(include area code)* |
| U | U | U | None | 30 | |

**Standard Form 298 (Rev. 8-98)**
**Prescribed by ANSI Std. 239.18**