INSTITUT POLAIRE

CONCORDIA PROJECT
INFORMATION ON THE SURFACE TRANSPORT SYSTEM
SET UP FOR SERVICING THE DOME C SITE

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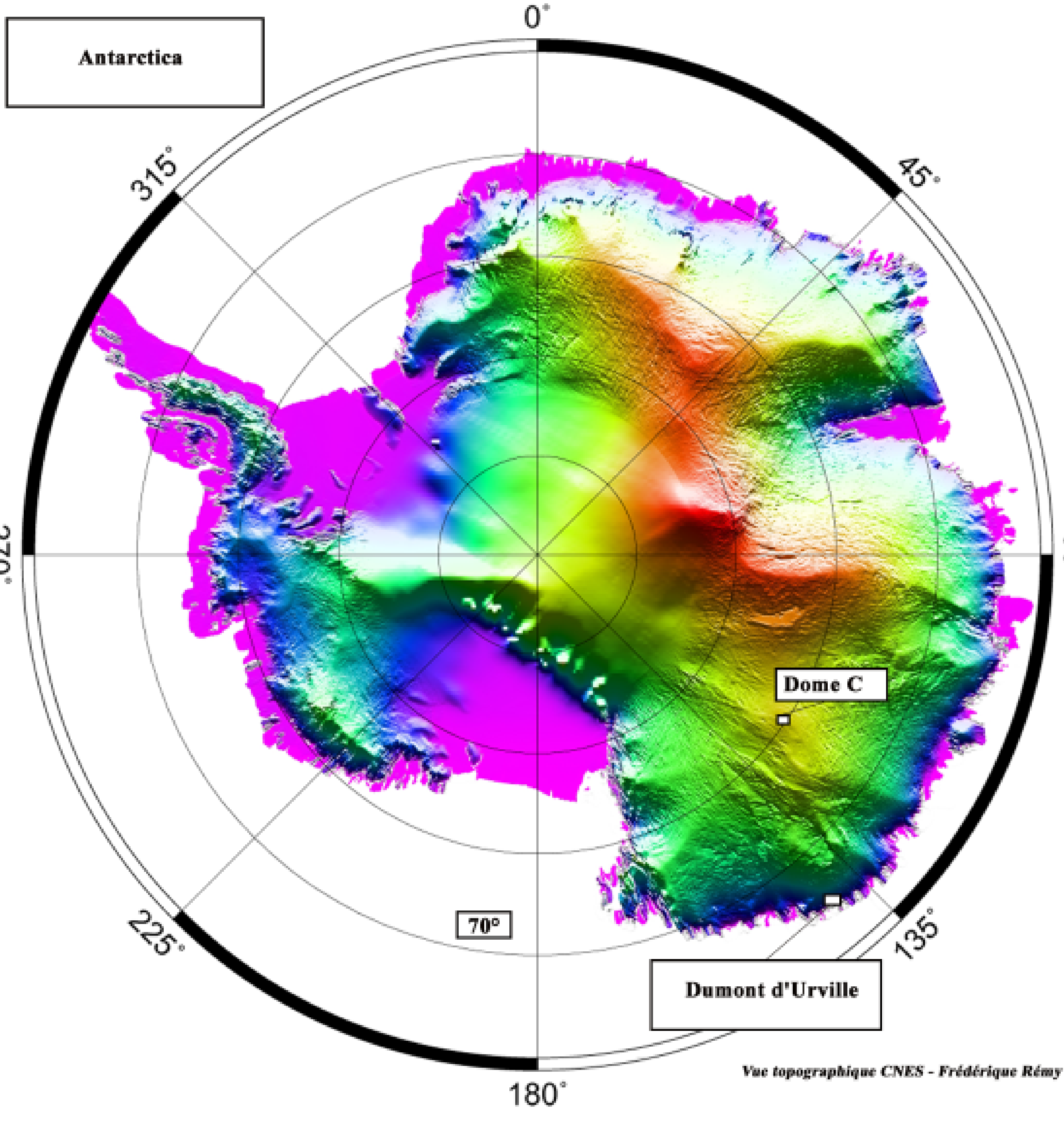
Antarctica
0°
45°
90°
135°
180°
225°
270°
315°
70°
Dome C
Dumont d'Urville
Vue topographique CNES - Frédérique Rémy

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This document presents the elements that guided IFRTP and its partner ENEA in their initial choices of traverse equipment and the results obtained.

A. Background

The French Polar Expeditions, parent organization of the current French Antarctic Program Operator IFRTP, had in their time acquired a reputation of excellence in the organization of traverses for scientific surveys or 'scientific' traverses. The object of these traverses servicing Dome C is different. These are 'logistic' traverses. The project to build a wintering station at Dome C (CONCORDIA) and the associated deep European ice core program (EPICA) involve the initial transportation of about 2,700,000 Kg of equipment to the site, 1,120 km inland. Then every year the normal operation of the site will require the transportation of about 300,000 Kg of supplies (food, fuel, various equipment).

B. Initial Requirements

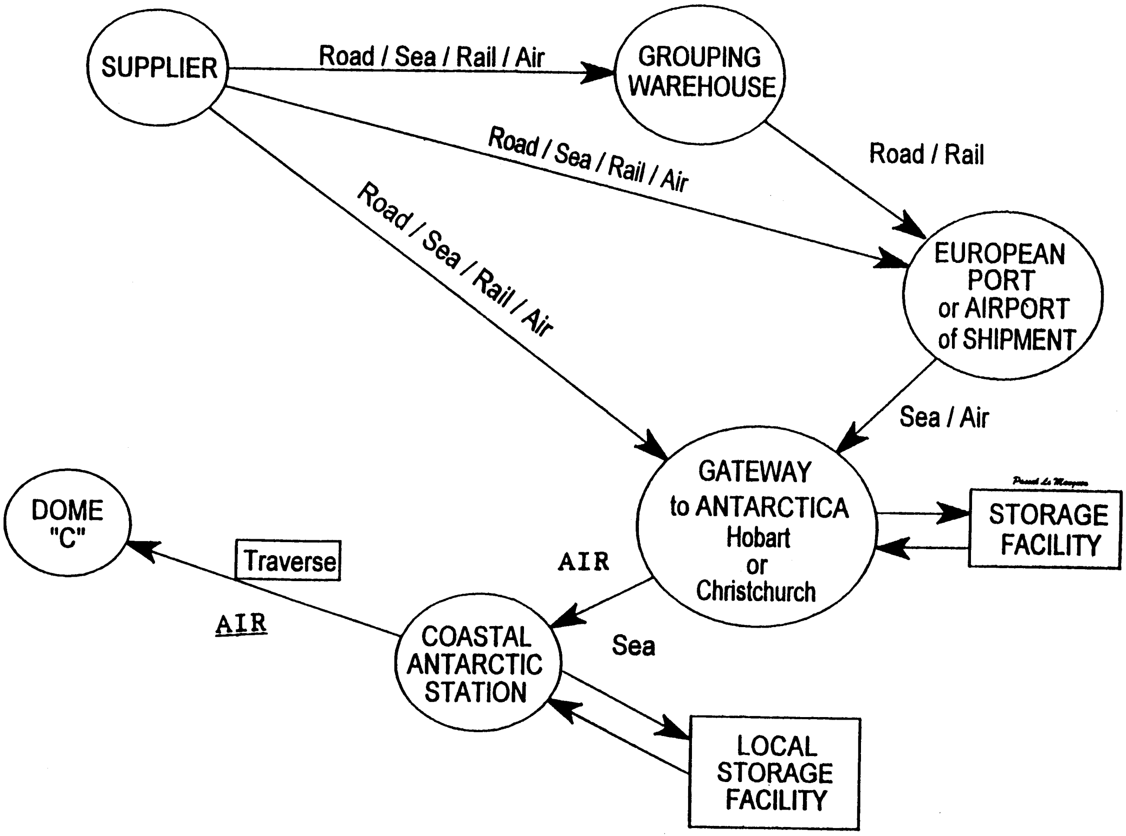
For several reasons, IFRTP and its partner ENEA made the choice of setting up a "traverse" surface transport system to service the Dome C working site. The characteristics of this surface transport system were dictated by:

- The acceptable net delivery rate;
- The departure point;
- The route used;
- The intermediate passage points;
- The point of delivery;
- The nature of goods to deliver;
- The transport personnel;
- The safety conditions.

The organization of the global transport operation, all the way from the manufacture or production site to Dome C is outlined in next page's diagram.

The operation of surface transport convoys on the Antarctic continent relates to the last step of this diagram. The logistic traverses can be assimilated to commercial transport operations in the sense that they have to:

- Deliver cargo **ON TIME**, and **IN GOOD CONDITION**;
- Provide a reliable routine service;
- Achieve the best **COST PRICE**.



Organizing the traverse operation involves finding proper answers to the following questions:

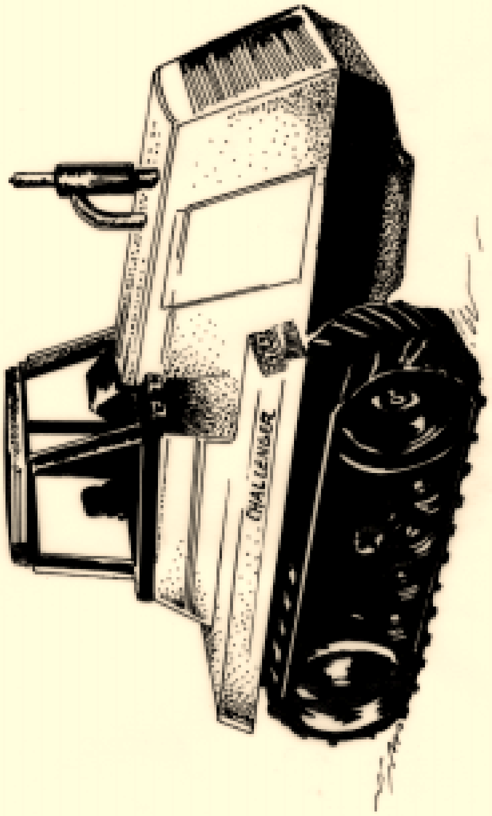
- What will the cargo be composed of, and what will the packaging be ?
- What transport vehicles will be used? What is the optimum delivery rate ?
- What drivers? How to satisfy their needs ?
- What solutions to the maintenance problems ?

C. Choice of Equipment

C1 – Basic packaging unit

To maximize efficiency, the basic packaging unit preferred for the traverse is the standard 20 foot shipping container. The sleds, trailers and handling equipment, including the unloading installations on the shore, were designed for the manipulation of such containers. Upstream, the items to send to Dome C are designed or selected for inclusion in 20 foot containers whenever possible.

Caterpillar Challenger Tractor



C2 – Vehicles

Two options were possible: load the cargo on the deck of a self-propelled vehicle, or load it on sleds or trailers towed by a tractor. In either case, there were no vehicles readily available on the world market for traverse operation. Our choice criteria were:

- Adaptability to the environmental conditions;
- Ease of use;
- Reliability;
- Ease of finding and obtaining spare parts close by (in Australia and New Zealand);
- Usability with respect to ground conditions (ground pressure, operational speed, ground leveling requirements);
- Load capacity, towing capacity;
- Fuel consumption.
- Costs

To allow a quick implementation of the transport system it was decided not to engage into designing a prototype, but to look for commercial vehicles to adapt to our requirements. We didn't find any suitable self-propelled decked vehicle responding to our requirements and the the choice of tractors useable on snow and ice in low temperatures is quite limited. Our search for tractors concentrated on:

- Civil engineering tractors ("pushing");
- Agricultural tractors ("towing");
- Ski field snow grading tractors;

while our search for towable load carriers concentrated on:

- Sleds;
- Tracked trailers.

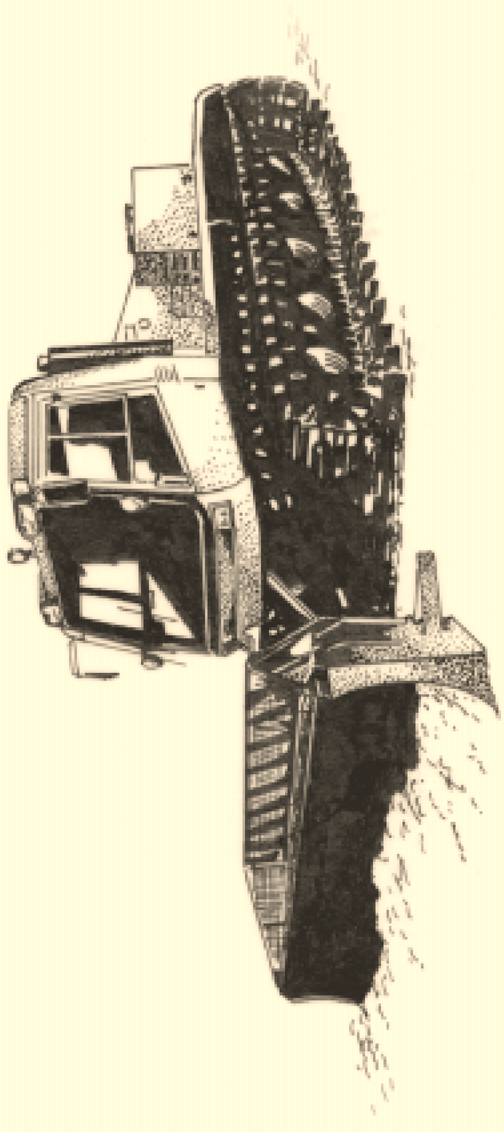
Tractors

At the time we started our investigations only 3 categories of tractors available on the world market called our attention:

- The Caterpillar D series "pushing" tractors (bulldozers);
- The Caterpillar Challenger series agricultural "towing" tractors;
- The Kassbohrer Pisten Bully (PB) series "snow grading" tractors.

The Caterpillar D series tractors, although being excellent machines, ended up being ruled out because of their high price and their low speed. The Caterpillar Challenger series tractors are agricultural tractors with rubber tracks designed to tow loads on soft ground. Simple modifications allow their use in summer on the Antarctic continent. The Kassbohrer PB series tractors are not towing machines. They are built to grade snow on ski fields and have an incomparable ability to work with their blade. They have a very low ground pressure.

levelling vehicle
Kassbohrer PB 330



The Caterpillar Challenger series tractors take advantage of the Caterpillar savoir-faire in civil engineering machinery. They have a low ground pressure (300 hPa), a powerful engine (215 to 230 kW), and a simple robust design. It is a conventional direct drive powershift transmission (hydraulic clutch, semi automatic gear box). The Challengers have an operating weight of 15,500 kg, a maximum speed (with no load) of 30 km/h and an operational cruising speed of 6 to 15 km/h when towing loads. They are designed to tow loads and it is possible for them to tow loads continuously without any durability problem. But they can lose some towing capability in dry "little-cohesive" snow. Being of simple robust design, they are low maintenance. They are not originally equipped with a blade, and attempts to fit one were not successful (pitching too important, lack of visibility). They can (mechanically) safely tow at maximum capacity as track slip will occur before any excessive mechanical stress. Towing at maximum capacity can occasionally cause the tractor to get bogged in irregular ground (bumps, Sastrugis...).

The Kassbohrer PB series tractors are snow grading machines designed for use in the ski fields. The PB 330 units are powerful (240 kW) to be able to push large amounts of snow and light (9,000 kg) to be able to go up steep slopes. The ground pressure is extremely low (60hPa) so that the machines won't compact snow too much on the ski runs. Transmission is via hydrostatic pumps and motors, with electronic controls. The blade, very easy to handle, is designed for snow. The maximum speed is of about 15 km/h with no load. They are designed to move on all types of snow, but lose some towing capability because of their low ground pressure on very light snow. Their technical sophistication makes them fragile for such a use far from well equipped workshops. The interval between major service operations, in Antarctica, is only of about 1,500h. Experience shows that towing heavy loads with a PB is damaging to the hydrostatic transmission.

Both types of tractors use under load about 6 litters of diesel fuel per kilometer. Under no load, the Challenger uses about 2 litters per kilometer while the PB, because of its hydrostatic transmission, uses about 4 litters per kilometer.

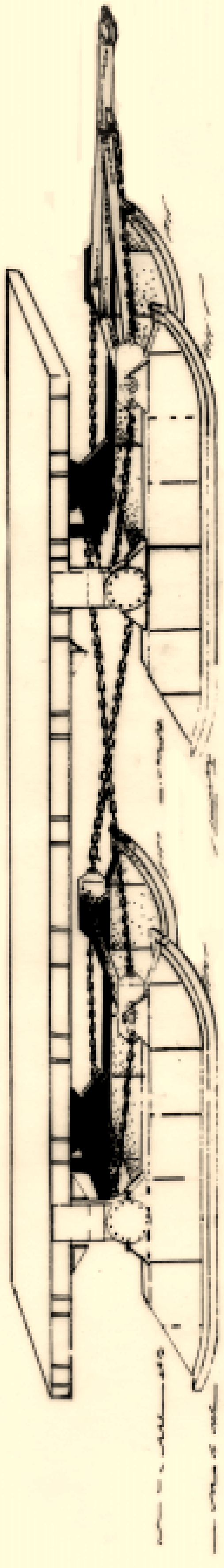
In summary: despite our desire to standardize equipment to simplify maintenance on the convoys, we concluded that these two tractors were complementary and we use them both: the Challenger to tow loads and the PB to grade snow and tow light loads in specific conditions.

Sleds

The traditional tow used to carry loads on snow or ice is the sled. The sled was invented in prehistoric times and preceded the wheel. By instinct the first designers had conceived a simple low ground pressure device taking advantage in snow fields of the low friction of the snow.

All traverses on ice caps have used sleds. If about every expedition had its own design of light sled, there are only few heavy sled designs. We have used Otaco and Aalener articulated models. We now use models of our own design: an articulated decked sled of 15 t capacity and a "tank sled" for bulk fuel. The tank sleds are dedicated to fuel, the product most transported on the traverse. The relatively small 12 m3 tank sits on a single pair of articulated

Classical decked sledge



skis via elastic devices. The tank sleds get a good net weight / gross weight ratio. In addition the tank sleds, with no moving components, save on mechanical problems.

Tracked trailers

If sleds are typically rustic devices, hence considered generally solid, they become fragile as you increase their size, capacity and moving speed (10 km/h is a high speed). Increasing reliability along with performance requires to list all points subjects to stress loads and either limit the number of fragile points or find technical solutions to avoid stress concentrations. This leads to a heavy design. The sled stops to be a reasonable option when you have to carry heavy loads.

Historically, rolling succeeded sliding. It makes sense to try to replace skis by a rolling system involving less towing resistance. Rolling on soft ground can be achieved using tracks. The tracks make the link between rotating wheels and the soft ground, spreading the weight over a large area to achieve low ground pressures. Tracks are a well known solution for traction in self propelled vehicles, but were practically unknown as passive option in towed vehicles.

The spread of passive tracks was triggered by the availability of continuous rubber tracks, appearing in the late eighties in catalogues of several manufacturers. Until then only existed tracks made of steel elements connected together or tracks made of elastomer strips placed side by side and mechanically connected. The continuous rubber track came with high mechanical reliability and on hard ground a lower resistance to motion than skis.

Facilities and living quarters

Traverse operation requires 15 to 16 hours of work every day and the personnel needs comfortable accommodation. Three units are assigned to personnel living needs:

The "Living" module is divided into two sleeping cabins, one surgery/radio room, one kitchen/dining room and one cold porch.

The "Store" module is divided in two rooms, one for provisions and one for spare parts. For a one month traverse, 1,200 kg or 2 m3 of food and drinks are needed.

The "Energy" module houses the generator set, the water production (snow melter) and distribution systems, the workshop, the bathroom and a warm store for medical supplies. The generator set rated at 65 kW powers the two "Living" and "Energy" modules as well as the tractor engine heaters during stops to keep machines warm.

A fuel pumping unit is located on the outside of the module and is used for refueling the tractors which need 4 m3 a day. The unit includes filtering and metering of the fuel.

12m decked trailer

Telecommunications

Each tractor as well as the "Living" module have fixed VHF transceivers for local communications within the traverse or with close parties. The fixed transceivers are completed by individual hand-held VHF radios.

The traverse has three different systems for long distance communications. An INMARSAT C is used to send by Telex position reports and other general work messages. An INMARSAT M is used for phone and fax, for both work and private communications. Traditional HF radio is used as back-up for INMARSAT but also for regular HF voice communications with the stations when out of range of the VHF system (about 20 km). There are three HF radio units, one in the "Living" module and two in different tractors.

Navigation

All of the tractors being equipped with GPS . There is also a theodolite, a solar compass and a Radar on the traverse.

C3 – Equipment at both ends of the traverse route

Each container or cargo bundle over 10 ton is loaded on a special, rudimentary “handling sled” in preparation for its loading on the convoys. A handling sled allows to handle and manoeuvre the load locally without the need for expensive or delicate equipment. The handling sleds are either loaded on the convoys with the cargo or left on the loading site which means that some units are needed at the delivery site.

Departure point (Cape Prudhomme – loading)

Dumont d’Urville, situated on an island, is separated from Cape Prud’homme, departure point of the traverses on the edge of the continent, by about 5 km of sea free of ice in summer. The personnel preparing the convoys is most of the time isolated from the station and must be self-sufficient. A base was created at Cape Prud’homme and includes living quarters, a powerhouse, two workshops, a 200m2 store, a 300m3 fuel farm and a 300m2 underground garage to shelter the vehicles in winter.

The personnel at Cape Prud’homme maintains the traverse equipment when not in use on a convoy and prepares all the cargo loads for the next convoy. Preparation of the loads is usually made using a 15 ton capacity electric gantry crane but can alternatively make use of the cranes mounted at the back of the Challengers.

Transfers of cargo between the ship’s unloading area and Cape Prud’homme are usually conducted over the ice in winter by Dumont d’Urville Station personnel but can also be conducted in summer using a 50 ton displacement barge unloaded using a fixed electric gantry crane installed on the shore.

Delivery point (Dome C – unloading)

All unloading operations are conducted by traverse personnel using the cranes mounted at the back of the Challengers and a Cat 953 track loader stationed at Dome C. If a load is too heavy for the cranes or the loader, the sled or trailer is placed in a pit with its deck flush with the snow surface and the load still on its handling sled is towed out onto the snow.

D - Organisation, personnel

The choice of the number of tractors in the traverse transport system was made on three different grounds: technical, psychological and financial.

Technical criteria included considerations such as convoy length, maintenance operations during stops, personnel accommodation requirements and breakdown probability.

Psychological aspects concentrated on the organization of a wandering group subject to a rhythmic routine. Both technical and psychological evaluations used our past traverse experience.
Large groups are more difficult to manage which hopefully combines well with the fact that too a large number of vehicles is difficult to operate and maintain. Our typical convoys include 7 load towing tractors and 2 snow grading tractors operated by a team of 9 to 10 persons. By experience this is manageable both in terms of personnel and in terms of vehicles.

D1 – The traverse team

The traverse team requires a specific personality and profile. It must be able to perform many duties: drive, level the ground, determine its position and navigate, eat well, communicate, maintain and fix equipment, attend patients and form a coherent, responsible team.

The work on the traverse

Some of the duties have to be fulfilled by all members of the team while some other duties only need to be fulfilled by one person.

- **Drive:** The team members must be able to drive a vehicle towing a load while being attentive to onboard indicators and instruments. They must in addition be intuitive and attentive to feel the machine and react promptly to any problem.

- **Level the Ground:** Four persons must be able to level the ground with the Kassbohrer's blade, continuously and well enough to provide a good track for the six tractors that follow. This leveling determines the speed of the whole convoy. It is an exhausting job and in normal conditions the operator should be replaced every four hours

- **Determine Its Position And Navigate:** Two persons must be able to navigate using GPS and understand simple astronomical phenomena. One person must be able to determine a position using a theodolite, the astronomical tables and a logarithm table.

- **Eat well:** One single person must be able to organise, proper meals for the team.

- **Communicate:** One person in charge of telecommunications must be able to use Inmarsat as well as HF radio equipment.

- **Maintain Equipment:** Seven persons (one per tractor) must be able to carry out basic maintenance on the tractors and their loads (refuel, clean, clear snow, maintain loads secure, check couplings).

- **Fix Equipment:** The traverse is a technical adventure with 220 kW tractors, a diesel generator set, 18 to 25 loaded sleds or trailers. Four persons must have sufficient experience to intervene on a fully loaded sled or trailer deck. At least four persons must be experienced diesel mechanics, one of them must have a good knowledge of the Kassbohrer's hydrostatic systems. One person must be a good welder, and another one an electrician/electronics specialist.

- **Attend Patients:** The presence of a medical doctor on the traverse is necessary.

- **Form a Coherent, Responsible Team:** In such isolation and difficult environment, the team must be coherent and responsible. This requires a careful choice of all members, but more importantly requires the presence of a very good assertive leader accepted by all, capable of taking initiatives and making decisions. This leader organizes the everyday life of the traverse and takes the decisions when problems occur.

Professional skills of the whole team

- **Four Diesel Mechanics,** for maintaining and repairing all mechanical equipment, with at least one skilled in hydraulics.

- **Four grading specialists** which can also have other skills (mechanic, navigator, etc…).

- **One Navigator and Telecommunications Officer,** capable of maintaining his equipment. This member is usually the electrician / electronician of the team. This position involves a fair amount of work during traverse stops.

- **One Medical Doctor,** who can possibly also be Navigator or leveling specialist. He is usually in charge of the cooking. It is common practice to keep the doctor away from dangerous activities.

- **One Traverse Leader,** It can be one of the Diesel Mechanics, but it cannot easily be the doctor. The traverse leader must have a good knowledge of the project. He must know all the equipment perfectly and be able to assess its condition in order to take the right decisions.

- **One "Open" Member,** who only has to be able to drive a tractor and have good physical abilities. This person can be a scientist doing en-route studies, a journalist that will report on his trip, a supplier of equipment, a VIP, a technician in training etc... He is usually there "au pair" rather than as a full staff member. It "opens" the traverse to the outside world by allowing various one-off members to join the team.

Social considerations

As previously mentioned, the traverse team must be coherent and cohesive. Its members must really work "together". The personnel turnover should be low while still allowing the creation of a sufficient pool of experienced traverse personnel. The problem is to create a pool of experienced, rigorous professionals and avoid the succession of strong personalities coming along for the adventure without caring for the group.

Both professional and personal qualities are essential. The cohesion of the team requires respect for each other, and the understanding that every action not carried out properly can result in extra work load, equipment failure and/or high risk situations for somebody in the course of future traverses.

Traverse work starts with the preparation of vehicles and loads before departing and ends with the conditioning of vehicles for the winter upon return of the last traverse of the season. Bad conditioning for the winter, rough operation of vehicles or postponed repairs will sooner or later show their due.

Training

It is difficult on the employment market to find people with personal and professional capacities that can make them good "traversers". There are no formal selection criteria, but we consider aptitude to the environment to be an important issue and we tend to give preference to people that have the requested professional abilities along with a successful wintering past in Antarctica or mountain work experience. Then, we complement their skills as required by additional specialized training sessions. Such sessions include specific training on the Kassbohrer PB and Caterpillar Challenger tractors organized by the manufacturers, navigation courses at specialized institutions such as the French National Geographic Institute or first aid courses.

D2 – Risk assesment

Identification of potential risks

Total safety can never be reached, but we are making every effort to reduce risks as much as possible. Risks can derive from:

- Crevasses
- Fire
- Loss of food stocks
- Loss of energy production systems
- A vehicle or the whole convoy getting lost

Bad weather and white out

- Cold, Altitude, Sun
- Exhaustion
- Psychological disorders
- Illness
- Physical accidents

Crevasses: There are hardly no crevasses between Dumont d'Urville and Dome C and all are concentrated in the coastal zone. We have very little experience in this domain.

Fire: Fire is the most serious risk as it can cause the loss of one of the three modules or one vehicle. To minimize risks, the main personnel facilities were divided into two modules that separate the energy production area from the living area. The two "Energy" and "Living" modules have no link and personnel has to go outside to get from one module to the other. The fuel tank for the generator set is on the outside of the Energy module. The third module is the "Store" which doesn't contain any dangerous combustible materials (no petrol, propane, diesel fuel...). The three modules are made of auto-extinguishing material classified "M0" or "M1". All electrical installations follow maritime regulations.

Loss of food stocks: This can be caused by fire or the accidental disconnection of the sled or trailer carrying the stocks. To prevent a total loss of the stocks, the food is usually divided in three lots placed in the living module, in the storage module and on a sled (safety stock).

Loss of energy production systems: This can be caused by fire or by a problem with the diesel fuel, such as congealing. To prevent total loss of energy production capabilities, the traverse has at least one 25 kva generator installed on a tractor, a separate propane stock, kerosene and petrol.
A vehicle or the whole convoy getting lost: The convoys now follow most of the time the old convoy trace made easy to follow. However, each tractor is equipped with a GPS receiver and each driver has had basic navigation training. In addition, one tractor is equipped with a radar and is always placed in a position where it can monitor the entire convoy.

In case there was a problem with the GPS system network itself and no visible old trace was available for reference, the navigator is capable to determine his position astronomically using the sun as reference.

Cold: The main risk is associated with the loss of heating capabilities following the loss of energy production systems. But there are also daily risks caused by loss of attention and risk awareness. *The briefing of new traverse members on this aspect is necessary. Clothes are appropriate and each person has sufficient amount of clothes to get changed as needed.*

Altitude: Altitude related risks are mostly for personnel reaching Dome C by plane, not by traverse. Nevertheless, there can be daily risks on the traverse caused by loss of attention and risk awareness, notably over-estimation of one's physical capabilities. *The briefing of new traverse members on this aspect is necessary. The traverse is equipped with a compression chamber since the 95/96 season.*

<u>Sun:</u> Sun related risks are mostly concerned with eyes and possible serious ophthalmia due to UV radiations, and personnel is provided with adequate sun glasses. *The briefing of new traverse members on this aspect is necessary. On the forward leg to Dome C, "night sun" is especially problematic for drivers as it is at windscreen height.*

<u>Exhaustion:</u> Exhaustion is highly dependent on the schedule adopted, the environmental conditions and the problems encountered. *The medical doctor and the traverse leader should assess the level of exhaustion of the personnel and the traverse leader has all latitude to adapt the schedule and work program to the situation.*

<u>Psychological disorders:</u> *These problems, or the possibility of their occurrence, should be detected beforehand in the selection process.*

<u>Illness:</u> Traverse personnel is subject beforehand to thorough medical tests. The first main risk is food poisoning. *Food stocks are checked and sorted every year, and storage temperature requirements for refrigerated and frozen products are carefully enforced.* The second main risk is an accident or illness requiring surgery under anaesthetic. The traverse doctor is capable of and has sufficient equipment to perform surgery under anaesthetics.

<u>Physical accidents:</u> It is one of the most delicate problems. Physical accidents that would have benign consequences in a normal environment can take dangerous proportions in the traverse environment. *Traverse personnel must be aware of their isolation and take special care in any activity.*

Associated Prevention Measures

Safety is absolutely essential. There are several methods to prevent accidents and minimize their consequences. The actions taken in this effect on the traverse are:

- Multiply the number of shelters in the convoy, spread clothes and sleeping bags.
- Spread food into several stocks
- Link all vehicles and shelters with VHF radio.
- Have several INMARSAT and HF telecommunication systems spread in the convoy and regularly check them.
- Have several GPS positioning receivers spread in the convoy.
- Have in the convoy enough Kerosene to refuel an aircraft coming for a rescue operation.
- Have a medical doctor on the traverse, have experienced personnel, train one or two traverse members at first aid techniques.
- Have medical facilities
- Have a radar

It is also worth mentioning an evident action: Use reliable vehicles and equipment that prevent to have the personnel living in permanent fear of breakdowns and being exposed to dangerous repair operations.

The traverse members have to be trained, informed and permanently aware of their situation. It can seem obvious, but we should still mention that on the traverse:

- In a blizzard, you should only go outside wearing sufficient clothing, and possibly attach yourself to a safety rope.
- You should never open the door of one of the modules while the traverse is moving (for the personnel on rest shift when the traverse operates on 24 hours a day mode).
- You should check before starting the convoy that every person is there and where they should be.
- You should respect the planned schedule for sending radio messages reporting the traverse position.

Safety can't be neglected but imposing excessive safety measures is not necessary as it could give a false impression of security. The environment is hostile and the traverse personnel should always feel it.

E – Technical Aspects – Improvements – Performance

E1 – Vehicle Pool

The pool of vehicles dedicated to the Concordia surface transport system is composed of:

- 7 towing tractors Challengers 65x
- 3 snow graders Kassbohrer PB 330
- 14 tank-sleds of 12m3 capacity for the storage and transport of fuel.
- 1 ‘living’ caravan
- 1 ‘power supply / workshop / ablutions’ caravan
- 1 ‘store’ caravan
- 1 temperature controlled cargo van (kept either cold or warm depending on the content)
- 3 multipurpose cargo trailers with a 12 m long deck and 25 ton capacity
- 7 multipurpose cargo sleds with a 6 m long deck and 12 ton capacity
- 7 specialized sleds for the transport of 20 foot units

A standard convoy comprises 6 or 7 Challenger towing tractors, 2 PB330 snow graders, the three caravans, the temperature controlled cargo van and about 20 to 25 various sleds and trailers.

E2 – Adaptation of vehicles to Antarctic conditions and to desired function

E2.1- CAT Challenger 65x, main winterisation modifications

Engine compartment:

Installation of a fuel priming pump, a water separator and a fuel line heater in fuel system, Addition of a man hole on the fuel tank, a water collector at the bottom and a drain pipe and tap.

Installation of a 12/24 v alternator and a 50 MT starter motor
Installation of Fleetguard heaters in all oil compartments et and tank type heater to cooling system,
Installation of a 220V electric circuit to feed the engine heating elements when the convoy is stopped, with external connector and protection switchboard
Installation of an additional oil sump to increase oil capacity and hence intervals between oil changes.
Installation of a cerium oxyde catalytic converter which connects to the air intake of the turbocharger. This reduces the carbon deposits in the cylinders and lowers the exhaust gas temperature

Cabin

Installation of a marine type roof escape hatch with adjustable hinge, including external handle and lock facility;
Manufacture and installation of a double glazed front windscreen (original curved unit is replaced by 3 smaller flat units fitted in an adapted frame);
Installation of heating air pipes around front windscreens;
Replacement of the glass rear wind screen by a thick, clear plastic screen (it is too large to allow the installation of a double glazed glass panel);
Installation of a new locker and silicon seals on the cabin door;
Installation of a pyrometer to monitor the exhaust gas temperature and electronic tachometer on the right hand side of the cabin;
Removal of all levers not used in instruments panels and of their mechanisms (except on one vehicle);
Installation of a bench type driver seat, with 2 rewinding safety belts. The bench is mounted on a KAB seat base;
Installation of a road truck type rearview mirror, mounted on the external handle of the right side of the cabin;
Installation of supports for external GPS and VHF antennas.

Frame, body, belts and bogies

Manufacture and installation of a new bonnet assembly to improve engine compartment sealing and insulation complete. The bonnet assembly has large openings and lift off doors for easy maintenance;
Manufacture and installation of a heavy duty roll up blanket for the coolant radiator air intake;
Manufacture and installation of a sealed sump cover with relocated dipsticks and filters and transmission guard group;
Manufacture and installation of a heavy duty battery box with 2 x 210 AH batteries and Fleetguard battery blankets. Batteries will are filled with acid density 1.3 kg/dm3 and connected to an external 24 V starting/charging plug;
Insulation of the Hydraulic tank;
Manufacture and installation of ice scraper for drive wheels;
Installation of silicone seals in drive and idler wheels;
Installation of metallic hubs on wheels;

Challenger tractor pulling trailer and sled

Extension of the tracks grousers by vulcanization of an additional strip;
Installation of silicone seals in belt tension cylinders.
Removal of the external traffic and indicator lights

It must be noted the mixed track tension system combining springs and compressed nitrogen is still not operating satisfactorily in low temperatures as the cylinder then loses nitrogen despite the fitting of silicon seals. The alternative solution currently envisaged is to fill the pression chamber with hydraulic fluid, linked to a nitrogen accumulator..

E22 – Kassbohrer PB 330s

Engine compartment

Modification of the engine air intake and exhaust system to include snow separator,
Installation of heaters in all oil compartments and tank type heater to the cooling system,
Installation of a fuel circuit made of Caterpillar elements (with fuel priming pump, water separator …),
Insertion of an external cutout switch on the 24V circuit,
Installation of a 220V electric circuit to feed the engine heating elements when the convoy is stopped, with external connector and protection switchboard.
Installation of a cerium oxyde catalytic converter which connects to the air intake of the turbocharger. This reduces the carbon deposits in the cylinders and lowers the exhaust gas temperature,

Cabin

Installation of a roof escape hatch, including external handle and lock facility,
Installation of two road truck type rearview mirrors,
Installation of a hand operated accelerator,
Installation of supports for external GPS antennae,
Installation of a pyrometer to monitor the exhaust gas temperature.

Frame, body, belts and BOGGIES

Manufacture and installation of a sealed sump cover
Replacement of the original batteries by heavy duty batteries, batteries are filled with acid density 1.3 kg/dm3 and connected to an external 24 V starting/charging plug
Insulation of the Hydraulic tank
Installation of 2 x 300 l fuel tanks, 1 x 50 l buffer tank with a water collector at the bottom and a drain pipe and tap.
Replacement of standard blade hoses by silicone hoses
Manufacture and Installation of double glazed front windscreen (original curved unit will be replaced by 2 smaller flat units fitted in an adapted frame).
Manufacture and installation of 2 narrower (1400mm wide), symmetrical tracks,
Removal of the snow cutter’s suspension and installation of a towing hook
Replacement of the inflatable bogie wheels by new wheels filled with compressible foam

Challenger pulling trailer and sledges

E3 – Additional equipment common to all tractors

Fitting of a 20 ton Hyster winch on one Challenger;
Installation of 3 hydraulic cranes of 11 tm capacity at the back of 3 Challenger tractors;
Installation on one Challenger tractor of a '35 kVA / 50 Hz / 3 x 400 V' electric generator driven by the equipment socket, as a backup for the caravan's generator;
Installation on 3 Challenger tractors of 3 x '4 kVA / 50 Hz / 220V' electric generators driven by the hydraulic pump;
Installation on the 4 Challenger tractors equipped with a generator of 4 pairs of 1 to 2 kW 220V projector lights;
Installation of a special plough on the equipment arms of one Challenger tractor;
Installation on one Challenger tractor of a radar, with a second tractor to be equipped in the future.
Installation of two HF radio transceivers on two Challengers tractors.

E4 – Tracked trailers

The first two trailers were equipped each with two pairs of MTS 73 undercarriages, they all have idlers made of inflated tires, rubber belts and bogies. Several small problems appeared au début, technically minor but disrupting for the operations.

The MTS idlers were equipped with tubeless tires. This technique used universally around the world showed its limits in Antarctica. We are using now tires filled up with foam. The density and the elasticity of the foam would be equivalent to the tire inflation pressure required (we could not use rigid tires that would give too much resistance to deformation).

The rubber the belt are made of gets stiffer below - 35 Deg. Celsius. This in addition to the thickness of the belt, to the thickness of the pitched grousers and to the "winding radius" of the 850 mm idler increases the towing effort. We have consequently replaced the original belts designed for operation on abrasive ground by thinner belts and as the presence of the grousers increase the towing effort we have purchased thin smooth belts on which we vulcanized our own, smaller grousers. .

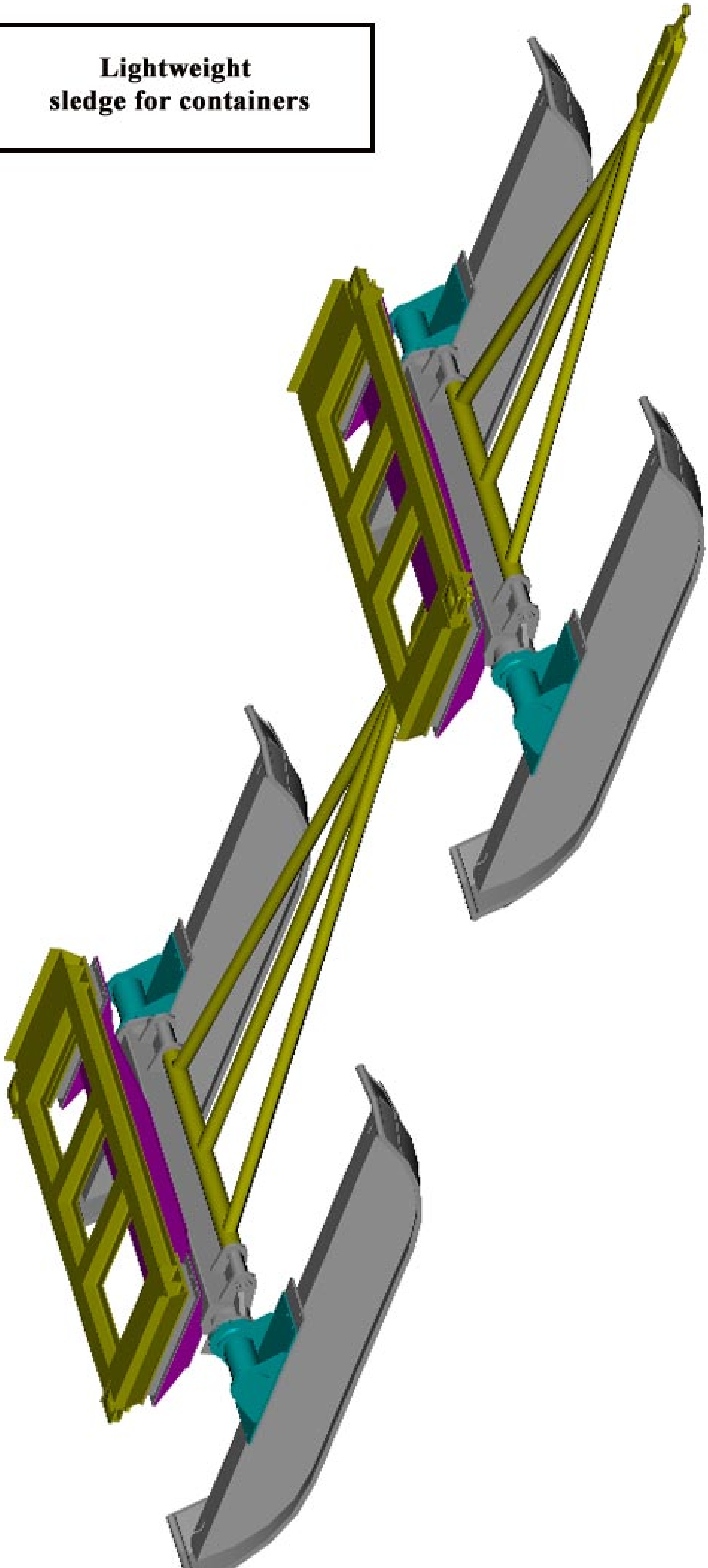
Note on the VFS 50 undercarriage

The 73 inch long MTS73 undercarriage used originally is too short to allow a low ground pressure when the trailer is sufficiently loaded. Therefore we installed MTS73 undercarriages at the front of all trailers and installed at the back longer 116 inch long MTS116. But the MTS116 showed some fragility in their main beam and they were replaced by 116 inch long undercarriages of the VFS50 series. The VFS50 units have been equipped with rubber bands on the steel wheels and silicon seals on bearings.

Another interesting advantage of the VFS units is their low price, half the price of the MTS116 units. The VFS series are manufactured by the Caterpillar Agricultural Division while the MTS series are manufactured by the Caterpillar Defense Division. It must be noted that while Caterpillar advised against the use of the VFS series in Antarctica, the VFS units have to date not presented any major problem.

The tracked trailers with their loads usually present a 2.0 net payload to deadweight ratio.

Lightweight sledge for containers



E5 – Sleds

Cargo sleds

Trailers are heavy and typically have a low net payload to deadweight ratio. Trailers should only be used for dense loads and there is place for improved sled designs to carry light loads (maximum 12 000 kg) such as empty construction modules or insulation panels.

The kinematics of articulated sleds requires the longitudinal mobility of the front ski assembly under the deck. Depending on the load, this movement can induce very high efforts in the axles. It is why we have designed sleds where the different components are linked with elastic couplings to allow relative movements during travel and to control efforts.

On one model of sled we have suppressed the deck to save weight and use the load itself, usually a 20 foot container, to provide structural strength. On this model, the front and back ski assemblies are linked by a drawbar instead of chains. This sled is one of the simplest ever built with only 12 different types of elements.

This type of sled with its load usually presents a 2.5 to 4.0 net payload to deadweight ratio.

Tank sleds

The principle behind this specialised sled is the use of the tank as structural element linking the front and back ski assemblies. The tank sits via 3 pairs of elastic articulations (each providing a three degrees of freedom link) on two articulated skis. This sled is also built with only 12 different types of elements.

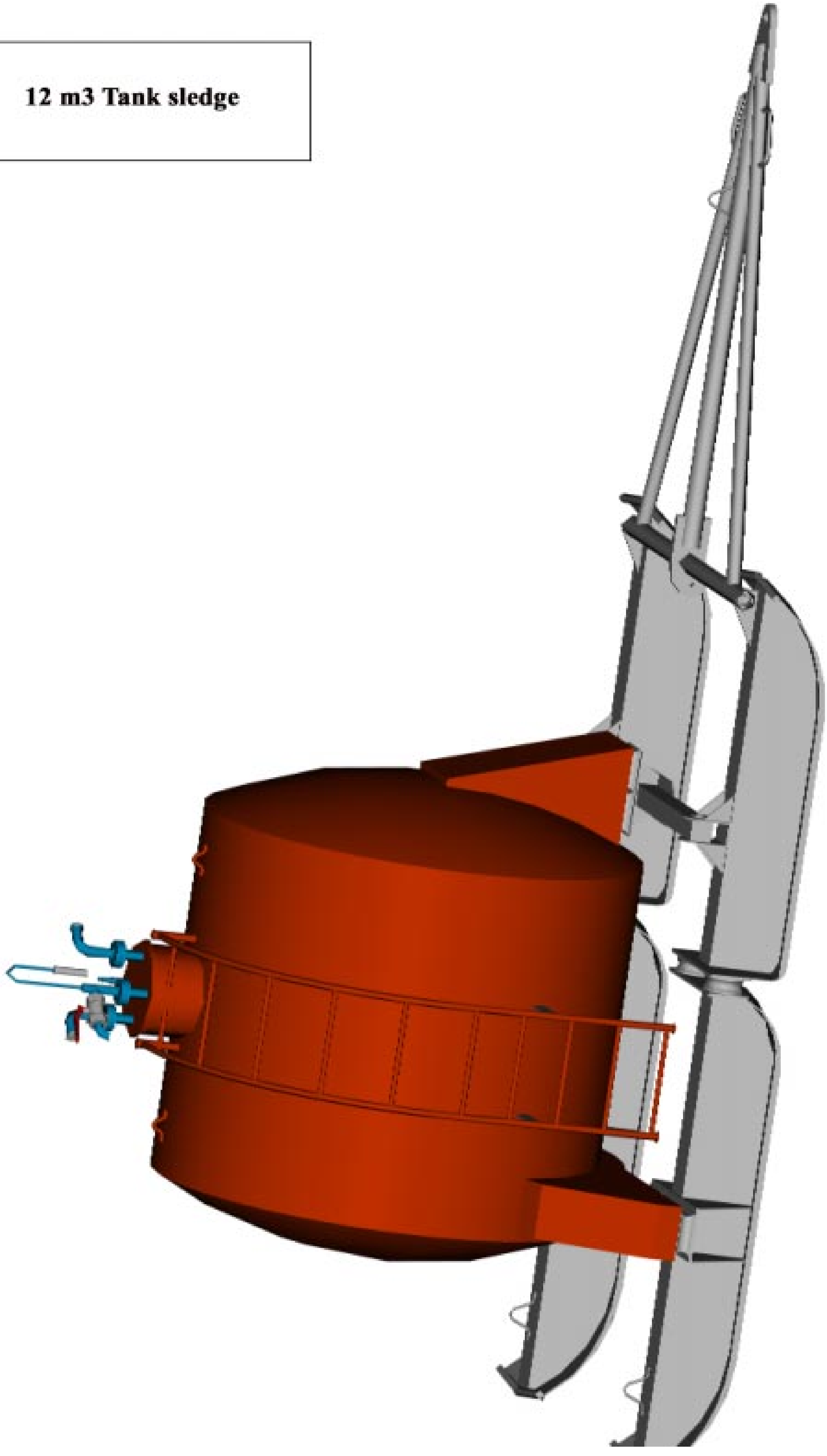
The 12 m3 tank is obtained by using standard components, with a 2,000 mm long, 2,400 mm diameter tube. The steel chosen for the parts that can suffer shocks and/or high stress is following French standard NF A48 FP (resilience measured at -50 deg C). The double skin configuration is achieved by deploying a flexible elastomer tank inside the steel tank.

The volume of fuel transported in each tank may seem low but it allows to leave behind near empty tanks very quickly and regularly, about one every day and a half, and to spread the fuel load equitably between tractors. Every tank left behind is still containing fuel to be used on the way back.

Leaving behind these tanks facilitates the progression of the convoy and automatically compensates for the loss of power linked to the increase of altitude and the loss of traction linked to the change of mechanical characteristics of the ground snow.

A full tank-sled presents a net payload to deadweight ratio of 3.5.

12 m3 Tank sledge



E6 – Cost and Performance

Performances :

13 return traverses have been already completed. The traverse reported here are traverses purely logistic not involved in any other works (glaciology, magnetism ...). The average duration of a return traverse to Dome C, including a 2 day stop on the site, is of 21 to 25 days (9 to 13 days for outward journey, 8 to 10 days the return).

The fuel consumption of a Challenger tractor depends a lot on the quality of the ground. Under full load the consumption varies between 5.5 and 8.0 litters per kilometer and while towing only empty sleds and trailers on the way back to the coast the consumption varies between 3.5 and 4.5 litters per kilometer.

Each season the cargo load delivered at Dome C is usually higher on the second and third traverses after the first traverse has compacted the track and improved traction conditions. It is then more meaningful to give a total cargo delivery figure for the season rather than give a figure per traverse. 407,500 kg were delivered to Dome C during the last season, and this total is currently increasing by about 10% every season.

The table shown on next page gives some statistics for past traverses.

Cost:

The analysis of the transport system costs makes a distinction between equipment and development costs. Development costs includes the cost of discarded equipment and the cost of modifications to equipment still in use. The costs are based on an average rate of 1 US Dollar (USD) for 6 French Francs.

Equipment cost:	4.2 Million USD
Development cost :	1.7 Million USD
Cost of Cape Prudhomme coastal installations:	2.0 Million USD
Cost of Dome C unloading installations :	0.5 Million USD

The cost of Cape Prud'homme coastal installations includes salaries costs for the construction of the installations, following French salaries rules. The operational costs of each season is not indicated as about half of it is made of salaries from France and Italy and the differences in rules and structures may not allow a meaningful comparison. It is the same for amortization costs.

When using the French calculation rules the overall transport cost is estimated at about 2.5 USD per kilogramme delivered at Dome c when excluding the development costs and about 3.0 USD per kilogramme when including the development costs.

GENERAL STATISTICS ON CONCORDIA TRAVERSE TRANSPORT SYSTEM

Traverse N°	Date pre transfer	Depart CPH	Arrive DC	Depart DC	Return CPH	Gross Weight (t)	Payload ex-CPH	Payload delivered at DC	Fuel used (m3-t)	Duration (days)	Net cargo flow (t/day)	Efficiency Payload / Gross
04		16-01-97	29-01-97	31-01-97	10-02-97	420	187	125	75/60	27.0	4.63	0.30
05		16-11-97	02-12-97	04-12-97	13-12-97	374	160	99	74/59	27.1	3.65	0.26
06		20-12-97	02-01-98	03-01-98	12-01-98	384	165	115	63/50	24.5	4.70	0.30
07		16-01-98	26-01-98	28-01-98	06-02-98	392	173	123	62/49	20.8	5.92	0.31
08	17-11-98	20-11-98	03-12-98	05-12-98	13-12-98	377	164	109	68/55	23.4	4.65	0.29
09	19-12-98	21-12-98	04-01-99	06-01-99	14-01-99	439	188	129	74/59	24.1	5.35	0.29
10	17-01-99	18-01-99	29-01-99	31-01-99	09-02-99	428	194	129	81/65	21.6	5.97	0.30
11	16-11-99	19-11-99	02-12-99	04-12-99	12-12-99	421	186	119	84/67	23.3	5.10	0.28
12	17-12-99	19-12-99	28-12-99	02-01-00	11-01-00	486	223	157	83/66	23.0	6.83	0.32
13	15-01-00	16-01-00	26-01-00	28-01-00	06-02-00	473	208	131	96/77	21.2	6.18	0.28

Notes:
- Weights are in metric tonnes (t), volumes in cubic metres (m3) and durations in days
- ‘CPH’ is short for Cape Prud’homme, ‘DC’ is short for Dome C

F – Ongoing technical improvements, efficiency increase

F1- Current system

The 10% annual increase in net cargo delivery was due as much to the improvement of the Challengers' traction (raising of grousers) than to the reduction of the resistance to traction exerted by sleds and trailers (general design, fine tuning). A special effort was also made towards the better distribution of the types of loads within the convoy, the use of tractors in tandem and the use of elastic liaison elements.

Each modification had to be tested and validated, then progressively extended to the rest of the vehicles. For example the raising of grousers took three seasons to complete. The alignment of all trailers and sleds on the latest standard should still take two more seasons.

The old convoy trace is usually found again every season through the use of marking tricks but its ground quality still fails to come up to expectations. A special effort will now be made towards the improvement of its consistency and macro-geometry. Work and tests in that direction started during the 1999/2000 season. The convoy now includes at the back a snow grader preparing the ground for the next passage. The time interval between the grading and the passage of vehicles should allow a good hardening of the surface. This should be reinforced by the introduction of a special plow to be used during the return trips towards the coast. The plow is designed to break and mix the upper parts of the soil at the back of the convoy just before the snow grader to obtain a more homogeneous ground.

The grading gives the trace a good geometry but it would obviously be even more effective if the trace was less pronounced. We are going to give some attention to methods reducing the impact of the convoy on the ground surface. We are mostly working on reducing the movements of tracks and skis and on coming back to a system guiding the head of the skis on rough terrain to prevent them from plunging into holes.

In the long run we are expecting with a harder and smoother surface an increase in convoy speed and a decrease in fuel consumption which will both contribute to an increase of the net cargo delivery capacity. This should also reduce wear and tear on the equipment.

Maintaining the schedule for 3 traverses per season requires a global organization were each action has been planned and timed in advance. This extends to the management of loading operations at the coast and unloading operations at Dome C, to the reduction of en-route maintenance operations (equipment reliability), to the organization of meals (all meals are prepared and divided in individual portions before the season in Europe and Australia). We are also currently testing several methods to raise the bad weather and visibility thresholds above which the convoy have to stop (powerful driving lights, glasses, marking of the edge of the trace ….)

F2 – 10 year plan

We did not want to start the setting-up of the existing transport system by the study of prototype powered vehicles because this process requires a lot of time and does not allow to mix design, validation and operation of the system.

Now that this system is operational we can in parallel work on the design of new vehicles. We are working on a concept mixing towed and self propelled vehicles where the head vehicle would produce electric power and feed it to electric motors fitted on the trailers under tow that would become partially self propelled.

This concept, used by railways, would allow an increase of the net cargo capacity per driver and a decrease in maintenance requirements by a reduction in the number of diesel engines. It would also significantly increase the potential for cleaner operations with minimum polluting emissions as it easier to prepare and control a single generator set unit than four vehicle engines housed under their bonnets.