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## THE USE OF ULTRALIGHT AIRCRAFT FOR MATERIAL LOCATION AND ROAD SURVEYS IN REMOTE RURAL AREAS

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### ABSTRACT

In many developing countries, there is currently a focused effort on providing or upgrading road infrastructure in remote areas. However, it is usually difficult to access these areas because of poor or non-existent roads, dense vegetation, the absence of river crossings and/or the presence of thick sand. Surveys of existing infrastructure are also very time consuming and the location of materials to construct new infrastructure is difficult. Too complicated matters, good quality, recent aerial photographs and maps are often not available. The best method available to conduct the various types of survey is thus by helicopter or fixed wing aircraft, although the higher speeds of fixed wing aircraft typically render this option unsuitable for certain functions. However, the costs of operating helicopters and fixed wing aircraft are very expensive and thus they are usually only used in the initial stages of projects for the basic surveys and thereafter all work is done from the ground.

In the past few years, use has been made of ultralight aircraft for undertaking a number of surveys in remote areas. These aircraft are safe and inexpensive to fly, while their slow speeds render them very maneuverable and open cockpits afford all-round visibility. Thus it is feasible and cost-effective for engineers, geologists and other specialists to regularly and cost-effectively fly the project to conduct surveys or to monitor progress and environmental impact.

Aerial surveys from ultralight aircraft have been successfully used in southern Africa for the location of road construction materials in remote areas and to plan the access routes to these locations. In two of the projects, conventional ground based material location techniques failed to locate any suitable sources over a period of a number of months. Both areas were flat, featureless and covered with thick layers of sand. One of the areas was arid with only scrub vegetation, whilst the second area was covered in tropical forest. No previous excavations were visible and no records of earlier material location exercises were known to exist. Ultralight aircraft surveys using botanical and geomorphological indicators in both areas located potentially suitable sources of materials in a matter of hours. Later ground investigations confirmed the presence of suitable materials.

In this paper, the use of ultralight aircraft for road surveys in remote areas is introduced. Botanical and geomorphological indicators and the development of guidelines for their use in southern Africa are discussed and the costs and benefits of using ultralight aircraft surveys in combination with these indicators as a means of applying this research in practice are summarized. Two case studies are presented.

## INTRODUCTION

In many developing countries, and even some developed countries, there is ongoing effort to provide or upgrade road infrastructure in remote areas, thereby improving accessibility for rural communities. However, it is often difficult to access these areas because of poor or non-existent roads, dense vegetation, the absence of river crossings and/or the presence of thick sand, heavy clay or rocky outcrops. Surveys of existing infrastructure and planned routes are also very time consuming, while the location of suitable materials to construct new infrastructure is difficult. Too complicate matters, good quality, recent aerial photographs and maps are often not available. The best method available to conduct the various types of survey is either by helicopter, which is very expensive or fixed wing aircraft, which because of their speed are unsuitable for certain functions. These aircraft are thus only used in the initial stages of projects, if at all, with most work being done from the ground.

Traditional techniques (ie map and aerial photograph based desk top study followed by ground survey) for activities such as route selection and material location are also often not appropriate in these areas, because of the lack of information, nature of the terrain, urgency, and possibly budgetary constraints.

In recent years, use has been made of ultralight aircraft for undertaking a number of road and material location surveys in remote areas in southern Africa. These aircraft are safe and inexpensive to fly, while their slow speeds render them very maneuverable and open cockpits afford all-round visibility. Thus it is feasible and cost-effective for engineers, geologists and other specialists to regularly and cost-effectively fly projects to conduct surveys or to monitor progress and environmental impact.

In this paper, some of the problems associated with surveys in remote areas are raised, details on various types of aerial survey are provided and techniques that can be used to optimize the survey are summarized. Two case studies are used to illustrate the process.

## PROBLEMS ASSOCIATED WITH SURVEYS IN REMOTE AREAS

There are numerous factors related to surveys using traditional methods that impact the successful delivery of road infrastructure projects in remote areas. These include, but are not necessarily limited to:

- A lack of quality topographical and geological maps, aerial and ortho photographs and satellite images covering these areas. This results in very little baseline information for the engineers to work with. Project costs usually limit comprehensive aerial photography and map generation. In recent years, the availability of Internet packages such as World Wind<sup>®</sup> and Google Earth<sup>®</sup> have greatly improved access to remote sensed images at little cost. However, the level of detail provided is still insufficient for all but basic planning for most types of project.
- Poor accessibility. Many areas in which new roads are being constructed are remote and often inaccessible due to the absence of infrastructure, suitable river crossings, thick sand or clay, and/or dense vegetation. Ground surveys are both difficult and time consuming under these conditions.
- Flat featureless terrain. Many undeveloped areas around the world occur on flat featureless terrain, where ground surveys using traditional techniques are difficult. These may be densely forested in moist tropical regions or barren in arid areas. Surveys from the ground, especially during material location are extremely difficult under these circumstances.
- Lack of local knowledge. In areas where infrastructure provision has been limited in the past, local inhabitants generally have no knowledge of the location of suitable materials or problem areas such as collapsing sands or heavy clays. The absence of existing borrow areas from previous projects exacerbates the problem when attempting to locate construction materials.
- Lack of services. In the remote areas of many developing countries there are little or no services (accommodation, fuel, supplies, etc) and hence lengthy ground surveys are logistically difficult and expensive to conduct.
- Thick overburden. In many areas thick layers of sand cover the underlying strata, which together with limited available knowledge of locally specific geology and flat featureless

- terrain, hamper the location of suitable construction materials.
- Landmines. Civil wars have been fought in many developing countries in recent times and many areas that are being opened up with the provision of infrastructure are still covered with them. Material and route location activities are extremely dangerous in these areas.
  - Environmental impacts. Many of the above listed issues also influence the ability to undertake comprehensive assessments of potential environmental impacts that will ensure that appropriate sustainable development can proceed. Specific issues such as impacts on drainage patterns, animal migration, habitat disturbance, etc are difficult to establish from limited ground surveys.

With the above in mind, alternative methods of conducting surveys in remote areas are often required. Some form of aerial survey is an obvious choice, given that they are not influenced by many of the factors listed above.

## **AERIAL SURVEYS**

### **Background**

Aerial surveys can generally be considered in four categories:

- Planning and environmental impact surveys
- Route location surveys
- Material location surveys
- Construction surveys

### **Planning and Environmental Impact Surveys**

Planning and environmental impact surveys are undertaken early in the project life cycle. Although much of the work can be done from aerial photographs and satellite images, an aerial survey will provide the engineer, planner and/or environmental practitioner with a full perspective of current conditions including land use, location of settlements, population densities, existing routes, potential growth areas, flora and fauna condition and population, migration patterns, etc. Specific areas of interest will include selecting optimal routes both from a functional perspective and for minimizing environmental impact, these being difficult and time consuming to accomplish from a ground survey. The study of drainage patterns is also simplified through aerial surveys and is particularly useful in areas where no flood data is available.

### **Route Location Surveys**

Route location surveys are similar to planning surveys although are more specific in nature. They are used to select optimal routes based on connectivity and avoidance of problem areas such as expansive materials, rocky outcrops, swamps, areas prone to flooding, etc. Optimal river crossing points are usually easier to identify from the air than from the ground. Potential ecologically sensitive sites, such as wetlands, indigenous vegetation, breeding habitats, migration routes and areas prone to erosion can also be identified and avoided.

### **Material Location Surveys**

Material location surveys are probably the most common survey conducted from the air. In many areas, the location of suitable materials is very difficult due to factors such as flat, featureless terrain or thick sand overburdens. Aerial surveys allow rapid transversal of the route and adjacent areas. Geomorphological and botanical indicators can be used to their full extent to identify potential sources. Numerous perspectives of the sites can be obtained by flying over them at different altitudes and from different directions. Features at known sources can be identified and then sought along the route. Indicators for material location are discussed in more detail below.

### **Construction Surveys**

Although not common, aerial surveys are also ideally suited to early construction surveys on

projects traversing long distances when driving along the route is still difficult. Regular flights allow engineers and environmental officers to assess progress, productivity and impact mitigation along the length of the project without the need for time consuming and often difficult driving. Costs of operating an ultralight are usually offset by the increased productivity of the engineer, environmental officer and other key personnel. If a dedicated pilot is retained to fly the aircraft, a cost-benefit analysis comparing the improved productivity of key personnel against the costs of the pilot and aircraft may need to be considered to justify the expense.

## **Aircraft**

### **Conventional Fixed Wing Aircraft**

These aircraft, although highly suited to aerial photography, are mostly too fast for detailed route selection, material location and construction management. They are also relatively expensive to operate and require a comparatively high level of technical support.

### **Helicopters**

Helicopters are ideally suited to surveys in remote areas. They can be flown at any speed, can hover over areas where longer inspections are required and can land in areas where fixed wing aircraft can not. However, they are very expensive to operate and require skilled pilots and technical support.

### **Ultralight Aircraft**

These aircraft have grown in popularity in recent years, primarily as recreational aircraft, but also increasingly for survey purposes. They are inexpensive to operate when compared to conventional aircraft, highly maneuverable, yet easy and safe to fly. Various configurations are available to suit most requirements. They are recognized and accommodated by civil aviation authorities in most countries. Other advantages include:

- Ultralight aircraft have short take off and landing requirements (60 m) and can operate from water if appropriate floats fitted are fitted
- Engines run on standard gasoline (ie aviation fuel, which is generally not readily available in remote areas is not required)
- General service parts are limited to filters and spark plugs
- Open cockpits provide all round visibility

Two popular ultralight configurations are typically used - weight shift ultralights (**Figure 1**) which have evolved from hang gliders and three axis ultralights which have evolved from conventional aircraft and are flown in a similar manner (ie controlled by joystick and rudder).

## **Indicators**

In addition to all the typical visual indicators commonly used by engineers in road and material surveys, geomorphological and botanical indicators are intensively used in aerial surveys to identify problem areas when selecting routes, and for locating construction materials. Botanical indicators have also been successfully used in locating groundwater, sensitive areas such as those susceptible to landslides and the most active clays in areas covered by expansive materials.

Geomorphological indicators are those indicators most commonly used in road planning and material location (Lawrance, et al 1993) and will not be covered in any detail in this paper, other than to point out that they are easily distinguishable when flying at appropriate altitudes.

Botanical indicators in road construction include trees, shrubs, flowers and grasses, although ferns and fungi may also be relevant. The presence of many plant species and even the nature of their growth often depend on the mineralogical and physical properties of the material on which they have become established. In the past, plant indicators have been used for the location of various minerals and metal ores (eg copper), however, minimal data on the use of these indicators for the location of construction materials appears to have been published. A study was therefore initiated to investigate this potential use (Jones, 1994).

The use of vegetation as a guide to mineralisation involves the study of the response of plants to their environment and includes two fields of study, namely bio-geochemistry and geobotany. Bio-geochemical methods depend on the chemical analysis of plants or humus to obtain evidence of mineralisation in the substrate, whereas geobotanical methods involve visual surveys of the vegetation cover in order to detect mineralisation by means of plant distributions, the presence of indicator plants, or mutational or morphological changes induced by excesses of certain elements in the substrate (Brookes, 1972).

The extent to which plants may be used in the search for minerals and road construction materials will depend on the nature and extent of the vegetation cover. The factors of vegetation response to geochemical conditions which have relevance to geobotany and remote sensing fall into three categories, namely; structural, taxonomic and spectral.

- Structural - morphological changes in plants under the influence of mineralisation are varied and include such factors as dwarfism, gigantism, mottling or chlorosis of leaves, abnormally shaped fruits, changes of colour in the flowers, disturbances in the rhythm of the flowering period and changes in growth form. Total plant biomass towards less dense or more open conditions is common in areas of ultramafic rock types. Chlorosis (the yellowing of leaves) is a common response to metal stress and other factors. Stunted vegetation is a typical reaction to changes in geochemical conditions and can often have implications for rock type discrimination and mineral exploration (Mouat, 1982).
- Taxonomic - taxonomic factors of geochemical response by vegetation involve the analysis and assessment of plant species whose presence or abundance are affected by geochemical conditions as well as by vegetation assemblages which are unique to particular parent materials or mineralogical anomalies. There are two principal types of indicator plants, namely universal indicators and local indicators. Universal indicators are found only on mineralised soils and will not grow elsewhere. They are usually rare and have limited distribution. Local indicators are species that grow preferentially on mineralised ground within limited areas but will also grow over non-mineralised ground in other areas. Such indicators are considerably more common than universal indicators but have the disadvantage that they are often only useful in limited areas. The use of plant indicators as a guide to mineralisation is complicated by the fact that the element which controls the distribution of the plant may be either the one which is sought or an associated element or condition, such as pH or water availability. A plant which has a direct response to the element is described as a primary indicator. When the response is indirect, the plant is known as a secondary indicator. During the course of the research undertaken on botanical indicators in road construction, the species identified were predominantly local secondary indicators.
- Spectral - Spectral factors of response include the manner in which vegetation interacts with electromagnetic radiation. The effects of this category may be traced to either structural or taxonomic factors. Techniques employing remote sensing are used to discriminate between vegetation types and, inferentially, between types of substrate. Inherent in such a strategy is the response of assemblages of plants to geochemical and other factors of the substrate, which will result in spectral differences in the vegetation which can be differentiated on remote imagery (Mouat, 1982). The use of spectral factors requires expensive remote sensing equipment and competent interpretation expertise and was not included in the study.

For road construction, references to botanical indicators in the literature are generally limited to the use of certain species with a high tolerance for calcium in the location of calcareous materials (eg limestone and calcrete or caliche). However, an investigation (Jones, 1990) of the vegetation around a variety of other known road material sources in South Africa, including ferricrete (laterite), granite, basalt, dolerite, syenite and sandstone, revealed that the presence of certain plant species was restricted to the immediate area of the source and not beyond. Location of similar growth patterns elsewhere in the landscape indicated similar materials. The study also revealed that morphological differences (height, number of stems, etc) in certain species provided an indication of changes in material or other relevant factors such as perched water tables, high clay contents or the presence of sodic soils. In certain instances, the presence of specific species indicated the absence of suitable materials. For example, in South Africa, *Acacia haematoxylon*, *Baphia massaiensis*, *Burkea africana*, and *Terminalia sericea* all indicate the presence of very deep sand and if no other indicators (eg *Catopractes alexandri*, *Grewia sp*) are observed in combination with the plants, the likelihood of suitable construction materials being located is remote.

In compiling guidelines for the use of botanical indicators in material location (Jones, 1990, Lawrance, et al 2000) the problem of dealing with species identification was considered. In the African sub-continent, there are more than 24,000 indigenous tree, grass and flower species, many of which are difficult to identify. A more in depth study revealed that, although correct species identification enhanced the process, by simply observing distinctive changes in the vegetation patterns, or in the individual plants (eg stunted growth, leaf colour, occurrence of multi stems) sufficient indication could often be obtained to delineate a change in the geology, and possibly a potential source of material. These changes could also often be identified from the air during aerial surveys and on aerial photographs. **Figure 2** shows *Catophractes alexandri* growing on calcrete material. This photograph was taken from approximately 200 m. The dense grouping of the plant and the general absence of other plants indicates a potential change in geology and species identification would not be necessary. This site was not identified in a prior ground study despite being relatively close to the alignment. The source ultimately provided sufficient material for more than 20 km of subbase and base construction.

Although botanical indicators can be a useful aid to traditional methods of material location, it should be noted that:

- The absence of an indicator species does not necessarily imply absence of the material, whilst the presence of the indicator does not always signify that the underlying material is suitable for road construction or maintenance purposes.
- Although there is never a guarantee that suitable road construction materials will be found in the survey, the use of the techniques presented enhances the ability of the prospector to either find suitable material, or know beyond reasonable doubt that no suitable materials exist.
- Human activity may result in changes to the natural vegetation, which could in turn also influence the use of botanical indicators. Activities such as firewood collection, clearing for agricultural purposes, overgrazing, fire, mining, etc. could all influence the occurrence of particular species.

## Techniques

The techniques used will vary from survey to survey, depending on the project requirements. For route selection, potential routes are usually selected from maps or satellite images. These are then systematically flown and problem areas sought along each and the best route then selected. Most problem areas can be located by simple visual observations, supplemented with botanical indicators where appropriate. Examples include:

- On projects where expansive clay is a potential problem, trees species growing on areas with the highest plasticity are similar to those growing on lower plasticity areas, but are often more stunted and/or multi-stemmed. In Africa, this is particularly relevant in areas where *Acacia* or *Colophospermum* species dominate. Routes can usually be selected to avoid the worst areas. These are often on slightly higher elevations or other geomorphological distinctions that are not easily distinguishable from the ground, but are clearly evident from the air.
- Areas with poor drainage are easily identified by changes in vegetation, specifically grass type, even when water is not present. Vegetation growing in the vicinity of perched water tables is often also greener and/or taller than the surrounding vegetation.
- Unstable ground on grassy slopes can often be identified by the presence of flowers or shrubs not evident elsewhere on a range of hills. Similar plants can often be seen growing near previous landslides.
- In areas with bedrock or pockets of gravel close to the surface, trees are often stunted or prone to wind damage.
- Generally any distinct change in vegetation (species or appearance) should be considered as an indicator/warning that should be considered in the follow-up investigation.

In material location projects, desk top studies should first be undertaken for the pilot and/or investigator to familiarize themselves with the geomorphology and vegetation. When flying the following procedure is generally used (**Figure 3**):

- i) The aircraft is flown approximately 200 - 500 m above the ground along the proposed alignment.

- ii) Any abnormalities in micro-topography (eg pan rims), vegetation (distinct change of species, dense thicket of one or two species, change in plant morphology (e.g. stunted or multi-stemmed)) or soil colour are sought on both sides of the route alignment. Where feasible, specific species are sought.
- iii) Once observed, the aircraft is flown to these areas and a closer inspection made from the air while circling the area. If the presence of known plant indicators are noted, GPS co-ordinates are taken and a rating given to facilitate and prioritise later site visits. Observations are usually recorded on a tape recorder through the aircrafts intercom system as writing is usually difficult, especially if the pilot is doing the survey. An example of the output from a survey is provided in **Table 1**.
- iv) After inspection, the aircraft is flown back to the alignment and the flight along the route continued until a new potential site is observed.
- v) Once the aerial survey is completed, the identified sites are visited and exploratory excavations made to confirm the presence of material, collect samples for testing and to delineate the extent of the source.

**Table 1: Example aerial survey summary**

Pit	GPS Coordinates	Characteristic			Distance from road	Comments
		Soil colour	Vegetation	Topography		
1	S18°13'48" E34°21'45"	-	✓✓✓	✓✓✓	1.0 (S)	Small rock outcrop. Potential for gravel and crushed stone.
2	S18°14'50" E34°22'20"	-	✓✓✓	✓✓✓	1.8 (S)	Very large rock outcrop. Potential for gravel and crushed stone.
3	S18°13'52" E34°25'12"	-	✓✓	✓	1.6 (E)	Ridge running parallel to the road in an approx E-W direction. Slight increase in topography and change in plant morphology.
4	S18°13'58" E34°27'14"	-	✓✓	✓	1.8 (N)	Ridge running parallel to the road in an approx N-S direction. Slight increase in topography and change in plant morphology.
5	S18°10'12" E34°29'05" S18°10'06" E34°28'14"	-	✓✓	✓✓	2.0 (N)	Distinctive hillock north of the road. Discernable change in vegetation, but no evidence of gravel or rock.*
6	S18°10'00" E34°31'02"	✓	✓✓	✓	1.2 (N)	Area of distinctly different vegetation. No change in topography.
7	S18°09'21" E34°32'02"	-	✓✓	✓	1.3 (N)	Slight increase in topography and change in plant morphology.
8	S18°08'17" E34°33'04"	-	✓✓	✓✓	1.2 (N)	Increase in topography in a bend in the river. Discernable change in vegetation, but no evidence of gravel or rock.
9	S18°07'39" E34°32'44"	-	✓✓	✓	2.0 (N)	Ridge running parallel to the road in an approx E-W direction. Slight increase in topography and change in plant morphology.
10	S18°08'34" E34°39'28"	-	✓✓	✓	0.5 (S)	Ridge running parallel to the road in an approx E-W direction. Slight increase in topography and change in plant morphology.

Pedogenic materials are probably the most easily identified using botanical indicators. Calcrete (caliche) and silcrete have high calcium contents and are thus indicated by calcium tolerant plants. Examples from southern Africa include *Catophractes alexandrii*, *Combretum imberbe*, *Dichrostachys cinera*, *Erioccephalus ericoides*, *Grewia bicolor*, *G flava*, *G flavescens*, *Maytenus senegalensis* and *Pechuel-loeschea leubnitziae*. These materials generally occur in shallow pans, which are difficult to spot in flat featureless terrain.



Ferricrete or laterite is often identified by plants that tolerate impeded drainage. In southern Africa, the occurrence of a particular species (*Stoebe vulgaris*) invariably signifies that lateritic material is present (**Figure 4**).

In construction surveys, the flight procedures will depend on the needs of the engineer. Typically, this would entail flights along the route, with slow circles executed over points requiring longer observation. Instructions to ground crews can be given through radio communication. Photographs can be taken as required.

## **CASE STUDY - TRANS KALAHARI HIGHWAY, BOTSWANA**

### **Background**

Economic developments in southern Africa and future plans for growth dictated the need for a corridor linking the port of Maputo in Mozambique on the east coast of Africa with Walvis Bay, a Namibian port city on the west coast. The 2,750 km corridor would ultimately traverse Mozambique, South Africa, Botswana and Namibia. Much of the Botswana and Namibian sections of the road traversed very sparsely populated, dry arid areas with only very basic infrastructure or vehicle tracks. The area is flat, featureless and covered with thick layers of mostly wind-blown sand (**Figure 5**). The vegetation is mostly scrub savannah and the only road construction materials are the sand and isolated deposits of calcrete (caliche) and arkose.

Without suitable aerial photographs, the contractor on one of the Botswana sections of the road resorted to a ground study. The lack of any roads in the area and the presence of thick scrub savannah vegetation hampered the investigation with no suitable sources being identified after two months of investigation. An alternative methodology for locating materials was thus sought to prevent further delays on the project.

A repeat ground study to locate potential botanical indicators was considered inappropriate, given the nature of the terrain, vegetation and lack of infrastructure. The alternative of acquiring aerial photographs of the area was also rejected as the costs and time requirements proved to be unacceptable, while available satellite images although useful for preliminary investigations, were of insufficient detail. Instead, an aerial survey was selected as potentially the most appropriate method. An ultralight aircraft was chosen as it was slow, highly maneuverable, and affordable to operate by comparison with a helicopter. Fixed wing aircraft were considered too fast for the type of visual survey required.

### **Procedure and Result**

Using the procedure described above, a 60 km section of the route was traversed in approximately three hours. A total of 11 potential sources of material were identified in the area already surveyed in the earlier unsuccessful ground study. Six of these sites, selected at appropriate points along the route such that haul distances would be minimized, were visited in the following two days with a backhoe-loader. All of the sites were found to contain calcrete (caliche) of varying quality and quantity, between 1.0 and 2.0 m below the surface (within the limits detailed in the contract pricing). Samples removed during this expedition were tested in a laboratory and results showed that sufficient material of the required standards for the various pavement layers could be excavated. One of the sources was found to be suitable for use as surfacing stone in the chip seal design.

### **Benefit**

A three-hour ultralight aircraft flight using botanical indicators to identify potential sources, followed by a two-day site inspection, located sufficient material to build a 60 km section of road. A two-month field survey in the same area using traditional techniques failed to locate the sources. The time and cost savings of the alternative method are obvious. A simplified breakdown of the costs is provided in **Table 2**. Existing infrastructure (roads and a football field) were used for take-off and landing and no costs were incurred for strip preparation.

**Table 2: Simplified breakdown of costs for ground and aerial survey**

Item	Units/\$/day		Ground survey <sup>1</sup> (\$)	Ultralight survey <sup>2</sup> (\$)
	Ground	Aerial		
Geologist	60@560	3@560	33,600	1,680
Assistants	120@280	6@280	33,600	1,680
Vehicle	60@50	3@50	3,000	150
Backhoe loader	30@100	2@100	3,000	200
Subsistence	180@80	12@80	14,400	960
Ultralight	0@200	3@200	0	600
Ultralight pilot	0@500	3@500	0	1,500
<b>Total</b>			<b>87,600</b>	<b>6,770</b>
<sup>1</sup> No material located				
<sup>2</sup> 11 sites located, sufficient material for entire project from 6 sites				

## CASE STUDY - M1 HIGHWAY, MOZAMBIQUE

### Background

In Mozambique on the east coast of southern Africa, there is no direct north-south road. This is attributed to a prolonged civil war between 1975 and 1991 during which no development took place, numerous river crossings and an absence of suitable materials, given that much of the route traverses a flat coastal plain covered in a thick layer of sand. Post war reconstruction initiatives funded by various agencies focused effort in linking the north and south by road, however, considerable difficulty was experienced in locating suitable materials in many areas. The areas in question are generally flat, featureless and covered with thick layers of sand. The vegetation is either tropical coastal forest or grassland and the only road construction materials are the sand and isolated outcrops of igneous rock and weakly cemented (young) pedogenic materials. Material location exercises are hampered by the presence of landmines left from the civil war.

### Procedure and Result

A similar procedure to that described above was again followed. An 85 km section was investigated over a period of approximately 5 hours. Various altitudes were flown - initially higher to obtain an overall perspective of the topography and then lower in selected areas in order that outcrops under the tree canopy could be located. A number of igneous outcrops, which were not located in the earlier ground survey, were spotted and eventually 10 potential sites and access routes to the sites were located. Ground visits after landmine clearance revealed suitable base and subbase material in 6 of the 10 sites and suitable surfacing aggregate at four sites. During the aerial survey, what appeared to be previously excavated sites were observed. Later ground inspections revealed that the pits contained sand with a better particle size distribution than surrounding areas that was potentially suitable for subbase. Mechanical stabilization of the sand with weakly cemented calcareous material and silt, both also identified from the air, was also offered as an option for subbase construction.

### Benefit

A five-hour ultralight aircraft flight using botanical indicators to identify potential sources, followed by a two-day site inspection, located sufficient material to build an 85 km section of road. A field survey using traditional techniques but hampered by access problems and the presence of landmines, failed to locate the sources. Cost benefits are similar to those described in the previous case study. The aerial survey also limited the need to access areas with landmines.

## CONCLUSIONS

Numerous factors complicate the provision of infrastructure in remote areas of developing and even some developed countries. Optimal route identification and the location of materials are of particular concern. In recent years, aerial surveys using ultralight aircraft have been used,

primarily for material location, but also for selecting routes based on predetermined criteria, and for early construction surveys. Visual observations in conjunction with the use of geomorphological and botanical indicators form the basis of the survey.

In material location exercises, significant time and cost savings were attributed to the aerial survey. In these projects, prolonged earlier ground surveys had failed to identify any potential material sources. Later aerial surveys were able to locate sufficient material in a fraction of the time and an analysis of the costs revealed significant savings. In two examples presented, sufficient material for 60 and 85 km sections was located in surveys taking just three and five hours respectively. Earlier ground surveys over periods of approximately two months at each location had failed to locate the sites. Although there is never a guarantee that suitable road construction materials will be found, the use of the techniques presented in this paper enhances the ability of the prospector to either find suitable material, or know beyond reasonable doubt that no suitable materials exist.

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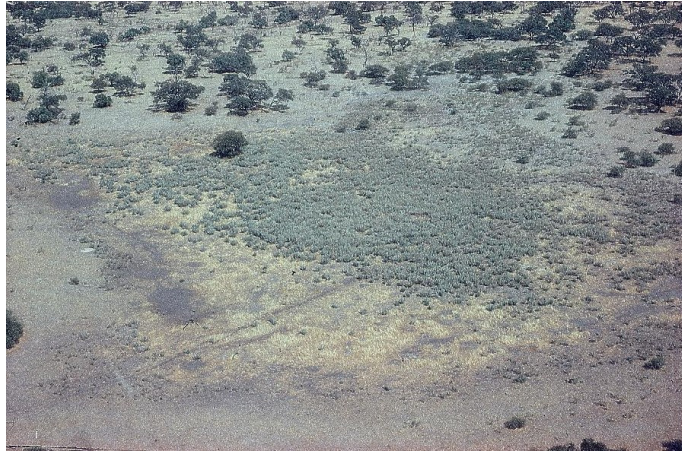
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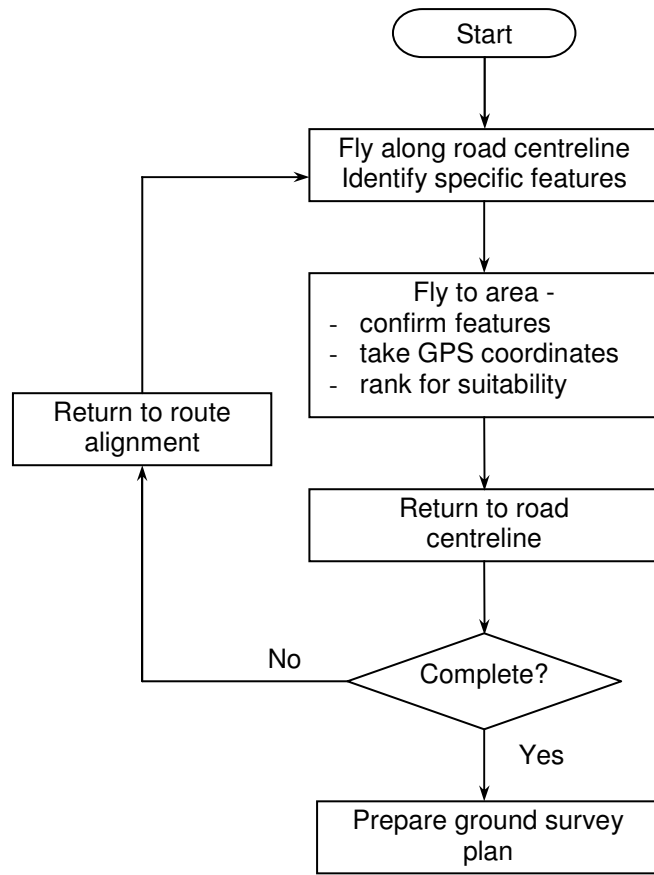
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**Figure 1: Weight shift ultralight aircraft**



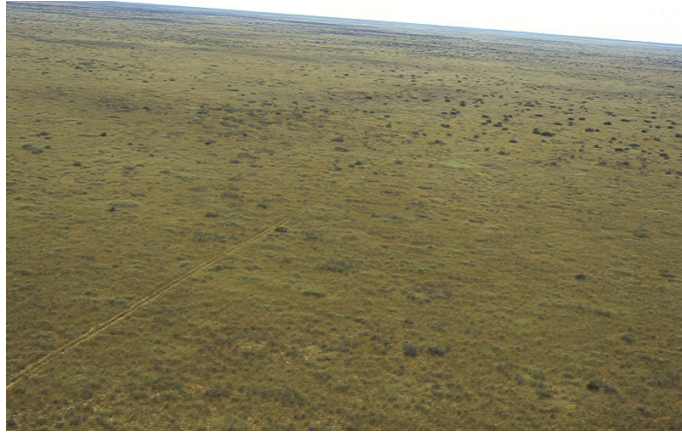
**Figure 2: *Catophractes alexandri* on calcrete pan**



**Figure 3: Flowchart for material location from the air**



**Figure 4: *Stoebe vulgaris* on ferricrete/laterite source**



**Figure 5: View of area to be crossed by the Trans-Kalahari highway**