An Alternative Approach to Measure Low Level Winds at Esrange

Sheikh Zahidul Islam
An Erasmus Mundus Master Course SpaceMaster

An Alternative Approach to Measure Low Level Winds at Esrange

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By
Sheikh Zahidul Islam

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Master of Science in Space Science and Technology

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Declaration of Authorship

I confirm that the work presented in this thesis is completely my own achievement and that any resources used in it are properly denoted in the reference section. It has not been submitted for any degree or examination requirements at other universities.

Kiruna, 31st October 2008

Sheikh Zahidul Islam
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Abstract

Esrange Space Center is one of the leading positions on the world map of launching facilities due to its launch services for sounding rockets and stratospheric balloons. When a rocket is launched from Esrange, all the way from ground up to 1000m is of great importance regarding the wind conditions and high resolution measurement. In order to determine the safety of landing and takeoff conditions, wind data is essential. Any rocket or balloon launch campaign at Esrange starts with the pre-flight preparations. Meteorological service is one the pre-flight services provided by Esrange before flight. Several meteorological systems are running at Esrange Space Center every day and night. Data collected from these tests are automatically transferred to a scientific data base. The measurement process becomes more intensive before each launch. These data (pressure, temperature and humidity) provides important information for the safety operation officer. During a countdown, meteorological balloons are launched regularly. ETAG (Esrange Throw Away GPS) is a new system developed by Esrange for wind measurement before any rocket launch. GPS position data from ETAG provides position coordinates and altitude information. Wind profile can be determined from the changing coordinates. Esrange ground station is used for communicating with ETAG. This means that Esrange is loosing a lot of quite expensive equipment for every wind sounding experiment as well as a balloon and Helium gas. So there is a need to define an alternative approach for low level wind measurement that would provide a relatively low-cost reusable system. Also the system will give the opportunity to measure the low level wind accurately at remote launch location.

This thesis discusses the feasibility of a new idea of research to find alternative method to measure low level wind. The new idea is to use a large motorized fishing reel. The fishing reel will release and rewind a 1000 m line. This will allow to reuse the whole set and also have the possibility of high resolution / frequency sampling. Also the balloon should move freely upward. That means the balloon should experience minimum tension while going up. A prototype of the proposed system was tested with 150m line and the result was compared with wind tower data. Wind speed and wind direction was determined up to 600m for seventeen meteorological balloons launched from Esrange. The advantages and disadvantages of the ETAG, motorized fishing reel system, and measurement procedures were identified and possible solutions were recommended. There were certain uncertainties and requirements which make the motorized fishing reel system design more complicated. Therefore the system was not built. Finally the thesis describes the possibility of a new system for low level wind measurement which can be used in future for further development of the pre-flight services at Esrange.
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## Abbreviations

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<td>Esrange Throw Away GPS</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>EGIS</td>
<td>Esrange Geophysical Information Services</td>
</tr>
<tr>
<td>SSC</td>
<td>Swedish Space Corporation</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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<tr>
<td>WWS</td>
<td>Wind Weighting Software</td>
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Chapter 1

Introduction

1.1 Esrange Space Center

Esrange Space Center [1] is one of the leading positions on the world map of launching facilities due to its launch services for sounding rockets and stratospheric balloons. It is located in northern Sweden, 45 km from the town of Kiruna at 67°N, 21°E. Swedish Space Corporation (SSC) supports the sounding rocket and balloon programmes of the member states of European Space Agency (ESA) and controls the Swedish satellite fleet from Esrange Space Center. SSC also provides technical services related to satellites operations and to the ground segment at Esrange Space Center. Most of the sounding rocket programmes launched from Esrange include educational rockets and other scientific sounding rockets. Figure 1 shows the location of Esrange in the map. [1, 2]
1.2 Preflight Tests at Esrange

Any rocket or balloon launch campaign at Esrange starts with the pre-flight preparations. Meteorological service is one of the pre-flight services provided by Esrange before flight. Several meteorological systems are running at Esrange Space Center every day and night. Data collected from these tests are automatically transferred to the SSC scientific data base called EGIS (Esrange Geophysical information Services). The measurement process becomes more intensive before each launch. These data (pressure, temperature and humidity) provides important information for the safety operation officer. During a countdown, meteorological balloons are launched regularly. Wind measurement is done from a 100 meter high wind tower. Figure 2 shows some pictures of meteorological services at Esrange. [3]

![Figure 2 Meteorological services at Esrange (From left to right: PTUsond (pressure, temperature, humidity), Wind tower (100 m) and Meteorological balloon [3](image)](image)

1.3 Objective and Outcome of the study

When a rocket is launched from Esrange, all the way from ground up to 1000m is of great importance regarding the wind conditions and high resolution measurement. In order to determine the safety of landing and takeoff conditions, wind data is essential. All stable unguided rockets will try to minimize the angle of attack, thus turning into the wind. An accelerating rocket will “cock” into the wind whereas a decelerating rocket will drift with the wind. This effect becomes greatest near the surface since the percentage effects
(weighting factors) are a maximum here, and the relative velocity of rocket is low. As high variability of wind is difficult to measure and forecast, the problem is complicated. This turning into wind becomes more important for impact prediction when large, multi-staged, unguided rockets are fired to high altitudes from short or zero length launchers. So the wind velocities near the surface must be measured accurately and continually up to as near launch time as possible, so that this information may be used in detail to predict the azimuth and elevation of the launcher. [4]

Two important factors are considered in the design of a launch vehicle are the nature of the winds encountered during ascent through the atmosphere and the response of the launch vehicle to winds. The horizontal wind through which the rocket must fly constitutes one of largest sources of load that the structure must resist. The product of the dynamic pressure and increased angle of attack induce very large bending moment on the rocket or launch vehicle. [5, 6]

ETAG is a new system developed by Esrange for wind measurement before any rocket launch. Also ETAG is used on big balloons for recovering gondolas and measuring position. GPS position data from ETAG provides position coordinates and altitude information. Wind profile can be determined from the changing coordinates. Esrange ground station is used for communicating with ETAG. As the balloon with the ETAG is lost after application this means that Esrange is loosing a lot of quite expensive equipment for every wind sounding experiment as well as a balloon and Helium gas. So there is a need to define an alternative approach for low level wind measurement that would provide a relatively low-cost reusable system. Also the system will give the opportunity to measure the low level wind accurately at remote launch location.

This opens the new idea to find an alternative method to measure low level wind. The new idea is to use a large motorized fishing reel. The fishing reel will release and rewind a 1000 m line. This will allow to reuse the whole set and also have the possibility of high resolution / frequency sampling. The balloon should move freely. That means the balloon should experience minimum tension while going up.

Various mechanisms have been identified and discussed in the thesis. The basic mechanism is a motorized fishing reel actuating mechanism and rod assembly. Support housing includes a rod and reel member and a mounting member extending perpendicularly from the rod and reel member. An elongated handle will mount gear housing and extend rearward with respect to the support housing. An electrical motor will be attached with the elongated handle. A power source is operatively coupled to the electrical motor and a drive train is operatively coupled to the electrical motor. A gear assembly is operatively coupled to the drive train and the fishing reel for winding a fishing line thereupon. This type of mechanism is now available as a final product for fishing. So instead of design and building the assembly, a commercially available one is proposed for the use. [38]

A prototype of the proposed system was tested with 150 m line and the result was compared with wind tower data. The prototype was a standard fishing line and rod assembly. But the selection of prototype was done by theoretical study and experimental conditions. The aim of the testing was to check the feasibility of ETAG to measure low level wind and accuracy of measurement. Also experimentally prove the theoretical calculation for line selection and how the fishing lines behave with various operational environments. As wind tower can
measure wind up to 100m, this give unique opportunity to compare the results and find the disadvantages of the system for further modification.

Wind speed and wind direction was determined up to 600m for seventeen meteorological balloons launched from Esrange. These seventeen meteorological balloons were launched before each rocket launched and hence the data is off great importance to study the precision of measurement of the system. The advantages and disadvantages of the ETAG, motorized fishing reel system, and measurement procedures were identified and possible solutions were recommended. There were certain uncertainties and requirements which make the motorized fishing reel system design more complicated. Therefore the system was not built. Further testing by building a small scale wind measurement system is recommended after modification of ETAG software. Finally the thesis describes the possibility of a new system for low level wind measurement which can be used in future for further development of the pre-flight services at Esrange.
Chapter 2

Low Level Wind & Balloon Dynamics

The aim of this chapter is to introduce the necessary information about the weather balloon and the physics to understand the forces acting on the balloon during ascending phase. Also the drag coefficient is explained in brief and some related literature have been reviewed and summarized in this chapter.

2.1 Low Level Wind

The Planetary Boundary Layer (PBL) can be observed as an interface layer between the free troposphere, where the dynamics can be described neglecting friction and wind field can be approximated by the geostrophic wind equation. This layer is characterized mainly by the increasing frictional influence towards the surface which leads to a transition from nearly zero wind velocities directly above the surface (a few mm) to the undisturbed winds in the free troposphere. [7, 8]

The PBL is divided into two sub-layers:
- The Ekman-Layer (~50-1000 m), and
- The Prandtl-Layer (~0.001-50 m).

The atmosphere is non-stationary with respect to the earth’s surface and its properties (e.g., density and temperature) vary with respect to time and altitude. These deviations of the non-stationary atmosphere from stationary position are termed as atmospheric disturbances. Among others, the non-stationary nature of the atmosphere is visible in the variability in the wind field on different timescales, including gusts. Wind is the three-dimensional motion of air. It is an inherently complex and random phenomenon. Wind speeds at the ground are small and increase with altitude. Gusts representing the turbulent nature of the wind field in the PBL are the small scale movements of air in the atmosphere whose occurrence at a specific time or place is unpredictable. Space Vehicles, prior to launch, are exposed to steady winds and gusts and to the turbulence wake from umbilical mast, gantry or other nearby structure. The response of vehicle to winds and turbulence produces oscillatory loads which must be accounted for in the design of the vehicle. However, only the horizontal winds significantly affect on vertically rising space vehicles and its design. Also the structural design of launch vehicles depends upon horizontal wind. To understand various meteorological problems such as turbulent diffusion, clear air turbulence, energy transfer, wave motion and forecasting, measurements of small-scale changes in the horizontal wind along vertical axis are needed. [7, 9, 10]
2.2 Wind Weighting

Wind weighting is an analysis tool. This technique used to predict launcher azimuth and elevation setting and correction for sounding rockets. The nominal drag impact point for the final launch vehicle stage can be predicted (trajectory prediction) using this technique. Flight safety officer must ensure that the current winds before rocket launch are within the pre-defined maximum values and variation limits.

The wind weighting analysis requires a six degree-of-freedom (DOF) computer program (input: launcher data, reference ellipsoidal earth model, vehicle characteristics for each stage, launch events, atmosphere, and wind errors) that can target an impact point. The analysis produces a 6 DOF trajectory which was computed using software.

On a launch day, the wind weighting processes includes the following steps:

i. Balloon with GPS is launched to measure the wind velocity and direction in regular interval. A wind measurement is done for every 50m or above layer from ground to the maximum altitude.

ii. Wind measurement is done up to a maximum altitude until the balloon burst. Maximum altitude wind is measured at least once every 6 hours.

iii. Wind measurement is done for medium altitude less than 20km in every 4 hours.

iv. Wind measurement is done for a low altitude less than 2000m. This measurement is required twice within every 30 minutes of launch.

v. Computer program is used to compute the launcher elevation and azimuth setting to achieve the nominal no wind impact point.

vi. Compute the impact point which result from wind drift for all intermediate stages by trajectory simulation.

vii. The launcher settings were verified within the established limits

viii. Verify the wind variation and maximum wind limits are within the launch constraints. [11, 12]

2.3 Weather Balloon

Large, smooth, superpressure, spherical shaped balloons are extensively used to measure vertical wind profiles in the atmosphere. These types of balloons are aerodynamically unstable and experience highly erratic motion when operating in the supercritical range of Reynolds numbers. A weather balloon is a special type of high altitude balloon which is used in the measurement and evaluation of atmospheric conditions. It is also known as sounding balloons. It carries instrument aloft to send back information (pressure, temperature, and relative humidity) which may be gathered during the vertical ascent of the balloon through the atmosphere. Weather balloons, which are made of flexible latex material or rubber, are filled with hydrogen or helium. The weather balloon may reach up to 40 km before it burst. The balloon thickness decreases with increasing altitude until it reaches the bursting altitude. On the other hand the diameter is expanded from 6ft to 20ft during ascent. Wind data is
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obtained by tracking the weather balloon by radar or navigation system (such as GPS). [13, 14, 15]

Figure 3 Meteorological balloon launch at Esrange [1]

2.4 Physics of a balloon ascend

Ascend of a balloon can be understood as a balance between two forces: The buoyancy which lifts the balloon, and frictional forces, which are slowing it down.

2.4.1 Frictional forces

Friction is a force that acts upon moving objects. It acts in the opposing direction to that of the moving object. So if an object is falling downwards, friction will act upwards. Air friction, or air drag, is an example of fluid friction. It is generated by the interaction and contact of a solid body with a gas. One of the sources of drag is the skin friction between the molecules of the air and the solid surface of the body. The skin friction depends on properties of both solid and gas. Another source of drag is the aerodynamic resistance to the motion of the object through the fluid. This source of drag depends on the shape of the body and is called form drag. As air flows around a body, the local velocity and pressure are changed. Since pressure is a measure of the momentum of the gas molecules and a change in momentum produces a force, a varying pressure distribution will produce a force on the body. For higher velocities and larger objects the frictional drag is approximately proportional to the square of the velocity. [7, 8]

\[ F_D = \frac{1}{2} \rho v^2 A C_d \]  

(1)
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where

\[ F_D = \text{Drag force [kg.m/s}^2] \]
\[ \rho = \text{Air density [kg/m}^3] \]
\[ v = \text{Velocity [m/s]} \]
\[ A = \text{Cross sectional area [m}^2] \]
\[ C_d = \text{Drag coefficient [dimensionless]} \]

The drag coefficient is around 0.5 for spherical object with laminar flow.

2.4.2 Buoyancy

Buoyancy provides an upward force on the object. The magnitude of this force is equal to the weight of the displaced fluid. The buoyancy of an object depends only upon two factors: the object’s volume, and the density of the surrounding gas. The greater the object’s volume and surrounding density of the fluid, the more buoyant force it will experience. If the buoyancy of an object exceeds its weight, it will tend to rise. When the balloon rises its volume will increase because the surrounding atmospheric pressure decreases with height. On the other hand the balloon’s weight remains the same. Hence, the average density of the balloon decreases less quickly than that of the surrounding air. As a consequence, the balloon’s buoyancy decreases because the weight of the air which is displaced by the balloon decreases with altitude. A rising balloon tends to stop rising. The Buoyant Force can be expressed using the following equation: [7, 8]

\[ F_B = V_B \rho g \]  \hspace{1cm} (2)

where

\[ F_B = \text{Buoyant force [kg.m / s}^2] \]
\[ V_B = \text{Balloon volume [m}^3] \]
\[ \rho = \text{Air density [kg/m}^3] \]
\[ g= \text{Acceleration due to gravity [m/s}^2] \]

2.5 Drag Coefficient

Drag Force and Reynolds number are commonly used as parameters to investigate the sphere motion. The drag coefficient is used to characterize the drag force. A body immersed in a fluid will experiences drag force due to relative motion between the body and the fluid. It is well known fact that any surface (such as balloon) in contact with a air is subject to a force exerted by the air. This force is commonly called a drag force. An expression relating to the drag force on a spherical shaped balloon immersed in air is easily derived by using dimensional analysis. [16]
Consideration of the physical factors which influence the drag force leads to the listing of the following as principal variables:

\[ F_D \quad \text{the drag force on the sphere} \]
\[ D \quad \text{the diameter of the sphere} \]
\[ u_\infty \quad \text{the free stream velocity of air} \]
\[ \rho \quad \text{the density of air} \]
\[ \mu \quad \text{the viscosity of air} \]

Therefore, the following equation may be written:

\[ F_D = f(D, u_\infty, \rho, \mu), \quad (3) \]

or, can be expressed using some constants,

\[ F_D = CD^a u_\infty^b \rho^c \mu^d. \quad (4) \]

Using the mass-length-time systems of units and substituting the proper dimensions,

\[ \frac{ML}{T^2} = L^d \left( \frac{L}{T} \right)^b \left( \frac{M}{L^3} \right)^c \left( \frac{M}{LT} \right)^d. \quad (5) \]

Since the dimensions must be the same on both sides of the equation, the exponents must be the same for each unit. Thus,

For M: \[ 1 = c + d \]
For L: \[ 1 = a + b - 3c - d \]
For T: \[ -2 = -b - d. \]

Solving these equations in terms of \( d \),

\[ a = 2 - d; \quad b = 2 - d; \quad c = 1 - d. \]

Thus,

\[ F_D = CD^{2-d} u_\infty^{2-d} \rho^{1-d} \mu^d. \quad (6) \]

Now, grouping variables according to exponents,

\[ F_D = CD^2 u_\infty^2 \rho \left( \frac{u_\infty D \rho}{\mu} \right)^{-d}, \quad (7) \]

The term \( \frac{u_\infty D \rho}{\mu} \) is a dimensionless group known as the Reynolds number. Regrouping, this equation can be rewritten in the general form

\[ \frac{F_D}{\rho D^2 u_\infty^2} = f'(\text{Re}), \quad (8) \]
that effectively reduces the number of variables to two dimensionless groups, which are, in turn, functions of density, viscosity, diameter, and velocity. By varying any one or more of these parameters, a correlation between the two groups can be formed.

An expression for the drag force on a body is usually given in the form

$$F_D = C_D A \rho u_o^2 \frac{2}{g_c}$$  \hspace{1cm} (9)

where,

- $C_D$ is a dimensionless drag coefficient,
- $A$ is the frontal area of the body exposed to the flow ($\pi D^2/4$ for a sphere),
- $g_c$ is the gravitational constant which allows the left hand side to be expressed in units of force.

This expression can be related to equation 8 by solving for the drag coefficient:

$$C_D = \frac{F_D 2g_c}{A \rho u_o^2} = \frac{8}{\pi} \left( \frac{F_D g_c}{\rho u_o^2} \right) = f^*(Re)$$  \hspace{1cm} (10)

Therefore, the drag coefficient itself is a function of the Reynolds number. [17, 18]

Large eddying wake form at low Reynolds number as transition and flow separation takes place near the equator of a sphere. The boundary upstream of the point of separation is laminar. The separation move downstream for increasing Reynolds number (laminar to turbulent flow) and reduced drag and wake is formed. Previous work on sphere motions and drag up to that time was summarized by Bacon and Reid [19]. Hydrogen filled rubber balloon rising in air showed highly erratic motion than those obtained in wind tunnel tests. Also the drag curves from different investigators were not consistent. Satisfactory explanation of the differences was not mentioned. But they found that it is impossible to get complete dynamic similarity as the Reynolds number of the tunnel changes with velocity. Hoerner [20] found that surface roughness plays an important role on sphere turbulence measurements particularly at supercritical Reynolds number. He also found that drag force becomes independent of the Reynolds number for very rough surfaces. Also Platt [21] and Roshko [22] extended the work which contributed to understand the relationship between bodies and properties of their wakes. Killen [23] concluded in his research that aerodynamic lift forces cause the erratic horizontal motions and small-scale changes in horizontal wind field could not be accurately measured by balloons. Later Murrow and Henry [24] confirmed his research findings. Preukschat [25] found that the wavy motions of rising sphere become more significant as the density ratio (density of the sphere to that of the liquid) decreased. MacCready and Jex [26] found that sphere motions depend directly on Reynolds number, density ratio, inertia, surface roughness and orientation. Scoggins [27, 28], MacCready and
Jex [26] and Rogers and Camitz [29] investigated the behavior of smooth, superpressure balloons and found that it is impossible to make accurate wind measurement using such balloons in the supercritical Reynolds number range. Timmerman and Weele [30] explain more about drag coefficient in their paper. Drag coefficient can be found using the following formula: which is valid for all $0 < \text{Re} < 2 \times 10^5$

$$C_d(\text{Re}) = \frac{24}{\text{Re}} + \frac{6}{1 + \sqrt{\text{Re}}} + 0.4,$$  \hspace{1cm} (11)$$

For a small value of Reynolds number the drag coefficient becomes $C_d = 24/\text{Re}$. [30]
Hoerner [31] shows graphically that $C_d$ is constant for a sphere for $\text{Re} = 10^4$ to $4 \times 10^5$ and the value is approximately 0.47. For $\text{Re} \geq 5 \times 10^5$, the value of $C_d$ is approximately 0.1. A sharp transition from laminar to turbulent occurs between $\text{Re} = 4 \times 10^5$ and $\text{Re} = 5 \times 10^5$.
Alvin [32] suggests using the following equations for large balloons which do not consider the change of shape:

$$C_d(\text{Re}) = 0.47 + \frac{24}{\text{Re} + 0.01},$$  \hspace{1cm} (12)$$

for $\text{Re} \leq 4 \times 10^5$

$$C_d = 0.3$$  \hspace{1cm} for $\text{Re} > 4 \times 10^5$
Chapter 3

Wind Measurement Systems

Various meteorological instruments are available to measure wind speed and directions. These instruments can be divided into two categories based on sensing techniques. First group are local sensing techniques which includes Anemometer, Rawinsonde, Weather balloon, Weather vane, Windsock and Pitot tubes. And the remote sensing techniques include SODAR, LIDAR, RADAR and Radiometers. As the main focus of this thesis is to use GPS method to measure wind speed and direction, only the GPS method is discussed in details. Also more information about ETAG is provided in this chapter.

3.1 GPS

High accuracy and precision of the wind measurements and world wind coverage are the major advantages of GPS based measurement, which is more popular nowadays. There are three types of NAVAID (Navigation aids) signals in use: (i) Loran-C, (ii) Very low frequency (VLF) systems and the (iii) Global positioning system (GPS). The GPS is a very high accuracy radio navigation system based on radio signals transmitted from a constellation of 25 satellites orbiting the Earth in six planes. Each of the orbital planes intersects the Equator at a spacing of 60°, with the orbit planes inclined at 55° to the polar axis. An individual satellite orbits during a period of about 11 hours and 58 minutes. [33, 34] The constellation of satellites is configured so that in any location worldwide a minimum of four satellites appear above the horizon at all times. The signals transmitted from the satellites are controlled by atomic frequency standards intended to provide a frequency stability of better than $1 \cdot 10^{-13}$. Each satellite transmits two unique pseudo-random digital ranging codes, along with other information including constellation almanac, ephemeris, UTC time, and satellite performance. The ranging codes and system data are transmitted using bi-phase digital spread spectrum technology. The power level of the ranging code signals is -130 dBm, well below thermal background noise. [33, 34] The following codes are taken into consideration:

(a) The coarse acquisition (C/A) code is transmitted on a carrier at 1 575.42 MHz. This is modulated by a satellite-specific pseudo-random noise code with a chipping rate of 1.023 MHz. This modulation effectively spreads the C/A spectrum width to 2 MHz;
(b) The precision (P) code, may be replaced by a military controlled Y code during periods when anti-spoofing (AS) is active. The P code and system data are transmitted coherently on carriers L1 (1 575 MHz) and L2 (1 228 MHz). [33, 34]
Figure 7 shows the NAVAID retransmission system. The GPS signals need to be preprocessed on the radiosonde to reduce the GPS information to signals that can be transmitted to the ground station on the radiosonde carrier frequency (either as analogue information, or as a digital data stream). The pre-processing can be achieved by a variety of techniques. Accurate wind computations require signals from a minimum of four satellites. In a differential mode, the phase or Doppler shift of the signals received at the radiosonde is referenced to those received at the ground station. This is especially beneficial when the radiosonde is near the ground station since location errors introduced by propagation delays from the spacecraft to the receivers or by AS are similar in both receivers and can be eliminated to a large extent. GPS tracking systems are able to track accurately at a very high sample rate. Thus, it is possible to measure the modulation of apparent horizontal velocity since the radiosonde swings as a pendulum under the balloon during a period of about 10 s. Upper winds at a very high vertical resolution (50 m) are not required for most purposes, except in the atmospheric boundary layer, and the swinging motions are best filtered out before the upper winds are reported. The main practical consideration with GPS radiosonde is the time taken for the GPS tracker on the radiosonde to synchronize to the signals being received from the satellite. It is unwise to launch the radiosonde until this synchronization has been achieved. This may require the radiosonde to be placed outside for several minutes before launch or alternatively a method arranged to transmit GPS signals to the radiosonde where it is being prepared. The accuracy of upper-wind measurements that can be achieved with NAVAID tracking will vary with the geographical location and navigational signals used. GPS wind measurements are of better accuracy than wind measurements by most other operational systems. One of the main advantages of NAVAID systems is the simplicity of the ground system, which does not consist of moving parts and does not need very accurate alignment of tracking aerials. [33, 34]


3.2 Esrange Wind Tower

Esrange uses 100m high wind tower to measure wind speed and direction. Measurements of wind are made at several levels. The wind tower is measuring data at 6 different locations: 10m, 25m, 45m, 65m, 85m, and 100m. The speed of wind and directions are easily obtained from EGIS website. Figure 8 shows the wind tower located at Esrange. The number of measuring levels depends upon both the task and the height of the tower or mast. The use of just two levels provides no information on the shape of the vertical profile of meteorological variables and is, thus, very limiting. The number of measuring levels is usually greater for research projects than for routine use. [3, 35]

![Figure 5 Esrange Wind Tower [3]](image)

The data from the wind tower are processed and presented automatically together with differences between the levels that are provided to characterize the meteorological conditions. The sensors most commonly used for measurements on tower are:

(a) Temperature: electrical resistance or thermo-couple thermometers in screens, with or without aspiration;
(b) Humidity: psychrometers, electrochemical or electromechanical sensors in screens;
(c) Wind: cup and vane, propeller, sonic.

Wind Observer II- Ultrasonic wind sensors are used in the Esrange wind tower to measure wind speed and direction. More specifications about the sensor are described in Appendix B. All sensors should have linear characteristics and their time constants should be small enough to ensure that the data gathered will reflect adequately local changes of the meteorological variables. It is important that the structure of the tower or mast should not affect the sensors and their measurements appreciably. [35]
3.3 ETAG (Esrange Throw Away GPS)

ETAG (Esrange Throw Away GPS) is a new system developed by Esrange for wind measurement before any rocket or balloon launch. Also ETAG is used on big balloons for recovering gondolas and measuring position. GPS position data from ETAG provides position coordinates and altitude information. Wind profile can be determined from the changing coordinates. Esrange ground station is used for communicating with ETAG. [1] ETAG produces localizations information using a GPS. The µ-Controller in ETAG can be programmed to receive and send data through an edge connector. Collected data and position data send out through an RF-link (Fig.6). [36, 37]

![ETAG build up diagram](image)

The heart of ETAG is a Fastrax iTrax03-s GPS which process and computes GPS position information, as well as provides an Atmega168 µ-processor running programs for data messages and collection. The GPS and the µ-processor are programmed via the I/O connector. ETAG has a power regulated system that gives opportunity to use external power or a 9V battery situated directly on the card. Power via USB connection can be used when the ETAG is programmed. More information about ETAG, data telemetry and ground station are provided in the appendix A.
Chapter 4

Analysis and Mechanical Design

The aim of this chapter is to introduce the necessary information about the new idea, balloon flight analysis and theoretical studies. The analysis starts with defining the test procedure and test conditions and further analysis continue later on. Also the chapter includes mechanical design of the system.

4.1 Analysis

The new idea is to use a large motorized fishing reel. The fishing reel will release and rewind up to 1000 m line. This will allow to reuse the whole set and also have the possibility of high resolution / frequency sampling. The balloon should move freely. That means the balloon should experience minimum tension while going up.

The basic mechanism will be a motorized fishing reel actuating mechanism and rod assembly. Support housing includes a rod and reel member and a mounting member extending perpendicularly from the rod and reel member. An elongated handle will mount gear housing and extend rearward with respect to the support housing. An electrical motor will be attached with the elongated handle. A power source is operatively coupled to the electrical motor and a drive train is operatively coupled to the electrical motor. A gear assembly is operatively coupled to the drive train and the fishing reel for winding a fishing line thereupon. There will be a variable control mechanism to control the speed of the electrical motor. [38]

The overall mechanism can be purchased as a single unit commercially. The background literature review and analysis of forces acting on the balloon will provide the specification for the overall system. The choice of tether (line), motor and reel rod assembly will be discussed later in this chapter.

The analysis starts with defining the test procedure and test conditions. It is important to know the test condition and compute the forces acting on the balloon. Once the forces are computed, the optimum line, reel and motor assembly can be easily found. Also the assumptions need to be well defined as the system parameters may be different with varying assumed condition. Once the assumptions are finalized, a suitable prototype will be tested before building the final system.

Some important system requirements were defined for the analysis processes which are listed below:

i. The ascend velocity of the balloon will be approximately 5m/s which is same as free balloon while going upward. Ascend speed less than the specified limit will not be acceptable.

ii. The balloon should be free moving upward. Minimum Tension in the line is preferred.
iii. The line used in the system should be capable to bring the balloon down to ground level. The line need to be tested experimentally before final system is build.
iv. The fishing line and rod assembly need to be tested before building the final system.

The scientific level requirements are as follows:
i. Present the data for wind speed and direction at different altitude. (wind profile)
ii. Validate the balloon borne data from ETAG with tower mounted instrumentation (Esrange wind tower) up to 100m.
iii. Accuracy of the wind measurement.

The tests conditions are identified through theoretical study and experimental knowledge gained through previous balloon launch. The test procedure is schematically shown in the following figures 7, 8 and 9. The critical conditions for the system are also identified which need to be tested during testing procedure.

Case 1:

![Figure 7 Test procedure (initial condition-case1)](image)

**Figure 7** shows that an ETAG is acting as a gondola for the system which is initially connected to the system. During launch the line will have tension and possible weak area need to be identified.
Case 2:

Now once the balloon is launched (Figure 8) the line will be released from the spool. Check whether the speed line released from the spool is fast enough to make the system as free as free moving balloon or not. That means almost minimum possible tension in the line. The balloon will move upward along with the wind direction. The selection of the line is so critical that it is going to add weight to the system and the may ascend slower than the actual target speed. So the line selection is one of the critical design parameter.

Case 3:
The major problem associated in the design phase is to consider the method and technique to bring the balloon down to ground level. With an ordinary fishing rod and line assembly, it is very difficult task. The selection of line is also critical as the line need to be strong enough to bring the system down from above 500 m to 1000 m. So the line should be thin and strong. Here critical factor is the motor and spool selection. The motor used in the system should have enough power to bring it back to ground level. Also as there will be high tension in the line, rewinding the line in spool may damage the spool (reel). These factors are discussed in the following flight analysis section.

**4.2 Balloon Flight Analysis**

Let us assume that the line used in the system will not experience tension or minimum possible tension while the balloon is ascending. Then the design should focus on a suitable spool (reel) selection and mechanism to release the line and the thickness of the line.

So the challenge will be getting the balloon back to ground level from case 3. Let consider the case 3, where it is clear from the Figure 9 that there will be high tension in the line. This tension need to be calculated and considered as it will affect the size of the motor to be used. The forces acting on the balloon in case 3 can be represented by the following Figure 10.

Meteorological balloon’s known parameters are needed to find all the forces acting on the balloon. The overall calculation process is done using SMWind Excel program which shown in the Appendix E.

For a given balloon, the following parameters are known or can be calculated easily [39]:

- Nominal inflation diameter, \( d \)
- Volume of the balloon, \( V \)
Mass of the balloon, \( m_b \)

Lift of Helium in standard air:
- Density of Helium
  \[ D_{He} = 0.18 \frac{gm}{liter} \]  

- Density of air
  \[ D_{air} = 1.30 \frac{gm}{liter} \]  

Buoyancy force:
\[ F_B = (D_{air} - D_{He})Vg \]  

Lift per volume can be calculated using the following formula:
\[ L = (D_{air} - D_{He})g = (1.30 \frac{gm}{liter} - 0.18 \frac{gm}{liter}) \times 9.81 \frac{N}{Kg} \times \frac{Kg}{1000gm} \times \frac{liter}{m^3} = 10.98 \frac{N}{m^3} \]  

So the lift of Helium in standard air \( \approx 11N/m^3 \) of volume.

Above information will be used to find the free lift of the present balloon model.

Now, the line weight of the line \( W_s \) can be found using the formula [39]:
\[ W_s = \mu L \]  

Where \( \mu = \) weight of 1000ft line and \( L = \) length of the line

The drag force can be calculated using the following equation:
\[ F_D = \frac{1}{2} \rho \nu^2 A \]  

Where
\( C_d = \) Drag coefficient [dimensionless]
\( \rho = \) Air density \([kg/m^3]\) = 1.23 kg/m³
\( \nu = \) Velocity \([m/s]\)
\( A = \) Cross sectional area \([m^2]\)

Free lift of the balloon [39]:
\[ F_u = \text{lift due to helium less weight of balloon and ETAG} \]
An Alternative Approach to Measure Low Level Winds at Esrange

Tension in the line:

The line follows a complex catenary curve due to its own weight. However, if we ignore the wind drag on the line then the tension at the top and bottom differ by the line’s weight. From Figure 10, it can be found that the horizontal and vertical component of tension will be as follows:

\[ T = \text{tension in the line as a function of line length from the balloon.} \]

- **Horizontal component:** \[ T_h = F_D \]  
- **Vertical component:** \[ T_v = F_u - W_S \]

So total tension can be found using:

\[ T = \sqrt{(T_v)^2 + (T_h)^2} \]  

These equations are solved to find the optimum thickness of the line and also choice of the motor. The tension will give the required power from motor, hence the design criteria for motor and structure. Selection of lines and commercially available motorized system are given in Appendix C and D.

Assumptions and simplifications made in the above equations are [these assumptions may vary for the practical situation which will be discussed in the next chapter]: [39]

- Wind is moving uniformly with constant speed and direction and no turbulence. Laminar flow is considered.
- Temperature is staying relatively constant and heating by sun is negligible.
- The density of air remains constant over the entire range of altitude.
- The string and ETAG experience negligible drag.
- The drag coefficient is approximately 0.5. [39]
4.3 Mechanical Design

Based on flight analysis, tether (line) and motorized system selection, the following two mechanical designs are proposed during initial theoretical study. The following figure shows the schematic of the mechanical structure with the proposed wind measurement system. The figures are drawn using CATIA V5.

Design 1:

![Figure 11 Mechanical design 1](image-url)
Figure 11 shows that the main mechanical structure is based on square frame and is supported by 4 legs. The legs are connected to the main frame using 90° angle connector and can be folded. This folding will make the system portable and easy to carry. The structure will be made of aluminum, so it will be light weight. But the structure will be strong enough to withstand the lift of balloon. The proposed Electra-mate 450 PTH system will be attached in to the 90° rotating plate. This plate is fixed to a rotating support which is fixed to the main frame. The position of the rotating plate can be change using the lever. Two possible situations may occur. Plate position will be horizontal and parallel to main frame when the balloon is launched. Plate position will be 90° when the system will bring the balloon down. The overall mechanical design is created considering the possible risk may occur and for long time operation. The following Figure 12 shows the 3 dimension sketch of the main mechanical structure and structural analysis.

Figure 12 3D view of mechanical design 1
The following area, volume and center of mass of mechanical design 1 are calculated using CATIA V5.

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<td>Author</td>
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Design 2:

Figure 13 shows that the main mechanical structure is based on circular main structure and is supported by 4 legs. The structure will be made of wood and aluminum, so it will be lightweight. But the structure will be strong enough to withstand the lift of balloon. The proposed Electra-mate 450 PTH system will be attached to the 90° rotating plate. This plate is fixed to a rotating support which is fixed to the main frame. The position of the rotating plate can be changed using the lever. Two possible situations may occur. Plate position will be horizontal and parallel to main frame when the balloon is launched. Plate position will be 90° when the system will bring the balloon down. The overall mechanical design is created considering the possible risk may occur and for long time operation.
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The following figure 14 shows the 3 dimension sketch of the main mechanical structure and structural analysis.

Figure 14 3D view of mechanical design 2
The following area, volume and center of mass of mechanical design 2 are calculated using CATIA V5.
Before starting the design and development of the final system, there is a need to study and test the feasibility of the research idea. An ordinary fishing line and rod assembly has been selected as a prototype. The idea is to check whether the data obtained from the test gives satisfactory results compared to data obtained from wind tower. Also, the line suitable for the system will be selected by these tests. Rubber balloon of weight 100 gm was selected for the test purpose. The average ascent speed of the balloon is approximately 5 m/s [based on the data obtained from previous experiment]. An ETAG will be on board for testing, and the data will be obtained from the ground station. As the wind tower can measure up to 100 m, the initial test plan is to go for that altitude and compare the results. Several tests were performed, and the results are discussed in the following sections.

5.1 Prototype Testing

The following fig. 15 shows the similar fishing reel and rod assembly used as prototype for the initial testing. Various fishing reel and rod assembly were used as prototypes and tested. Based on the prototype testing, several decisions were taken about final system design.
The reasons for selecting such type of fishing equipment for testing are as follows:

a) Cheap and easily available. Also various models are available to compare of rod design for the final system. Ideally the rods have a smooth, progressive taper from butt to tip. "Action” term often used to refer the responsiveness of the rod to bending force, and the speed with which the rod returns to its neutral position. An action may be slow, medium, fast or a combination. Fast Action rods flex most in the tip section. Slow rods flex more towards the butt of the rod. This feature of the fishing rod allows it to use for present testing. When the balloon reach a certain altitude, it is important to use some damping to stop it. Through our test we found that the rod act as a damper and also useful while line was rewinding into the spool. Rod minimizes the line force which can cut into the spool and may cause serious damage to spool after some experiments which is not desirable feature for any reusable system.

b) Spinning reel should be used same as the following figure. Opening the bail at the top of the reel allows free release of the line. It was check through present experiment that while balloon goes upward, the line is freely released from the reel and no tension in the line was observed to reduce the ascending speed. The anti reversing lever act as a damper to minimize the ascending speed after the balloon reaches the desired altitude. Drag is applied to the turning spool in order to act as a friction brake against it. Mechanical means such as a flat spring pressing against the edge of the spool, or as sophisticated as a complicated arrangement of leather and Teflon discs. As a rough general rule, drag is nominally set at about one-half of the line's breaking strength.

c) Also the fishing equipment allows fast change of line for reel. Various lines were tested to check the strength, drawbacks of the system. Modification and verification of the initial design was done through the tests. Also the initial test gives us data to compare with wind tower data.

The major findings through testing are described as follows:

Case 1 (Figure 7 Test procedure (initial condition-case1)):
ETAG is acting as a gondola for the system and balloon is initially connected to the fishing rod. During launch the line will have tension and possible weak area was identified. The knots are one possible weak area as two of the initial tests failures occur due the line cut. This implies that the balloon should be tied with knots strong enough to overcome the initial tension due to lift.

Case 2 (Figure 8 Test procedure (balloon moving upward-case2)):
Now once the balloon is launched the line will be released from the spool. From the present test it has been observed that the ordinary spinning spool release line fast enough to make the system as free as free moving balloon. That means almost minimum possible tension in the line. The balloon will move upward along with the wind direction. The selection of the line is so critical that it is going to add weight to the system and the may ascend slower than the actual target speed.
Case 3 (Figure 9 Test Procedure (Motorized system to bring the balloon down- case 3)):
The major problem associated in the design phase is to consider the method and technique to
bring the balloon down to ground level. With ordinary fishing rod and line, it was very
difficult task. The selection of line is also critical as the line need to be strong enough to bring
the system down from above 100 m. So the line should be thin and strong. Different lines
have been tested for this purpose.

5.2 Prototype Test Result

As discussed earlier that several test has already been performed up to 100 m and comparison
of data with wind tower has been studied. The learning from those tests is summarized below:

Test 1 & 2:
As it was mentioned earlier that test 1 and test 2 were failed because of following reasons and
the findings from the test give new way of approach to our current research:

i. The line used was not strong enough to withstand the initial pull due to
   free lift. The weakest point was the knots.

ii. The line should be thin also, otherwise it will add more weight to the
    system and the ascent velocity will decrease.

iii. From the test 2, it was observed that although changing line may
    minimize the initial pull due to free lift but after a while when the
    balloon reached a certain height, it was very difficult to use the brake
    and bring it to equilibrium position.

iv. 3 different types of conventional fishing line and rod assembly were
    used for the test purposes.

v. Through these tests, lines with various thicknesses were also tested.

Test 3 was the successful one. The prototype was tested for several times and the maximum
height of 100 m was finally achieved. As the wind tower height is 100m, the initial target is
to test the prototype up to 100m and compare the wind speed and direction with the wind
tower value. If the value matches and the measurement are precise for several test results,
then the final system will be built and tested.

To understand the test result, it is important to know how the data from ETAG is stored and
processed. The ETAG gives the altitude, wind speed, wind direction and vertical wind speed.
Data is stored in Esrange ground station computers and data is processed using wind
weighting software. ETAG is sending data in every second. The data obtained from the
ETAG is shown in the following sections and comparison with wind tower is shown also.
The way data obtained from ETAG is as follows:

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Source</th>
<th>Class</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/23/2008</td>
<td>07:32:38.338</td>
<td>SPRBEPOS</td>
<td>GPW</td>
<td>G</td>
<td>230608</td>
</tr>
<tr>
<td>6/23/2008</td>
<td>07:32:40.338</td>
<td>SPRBEPOS</td>
<td>GPW</td>
<td>G</td>
<td>230608</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Lat Dir</th>
<th>Longitude</th>
<th>Long Dir</th>
<th>Height</th>
<th>COG</th>
<th>HSPD</th>
<th>VSPD</th>
<th>Status of Data</th>
<th>CKSUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>6753.4180</td>
<td>N</td>
<td>02106.3423</td>
<td>E</td>
<td>330.3</td>
<td>359.6</td>
<td>0.49</td>
<td>5.2</td>
<td>6:01</td>
<td>0*74</td>
</tr>
<tr>
<td>6753.4186</td>
<td>N</td>
<td>02106.3429</td>
<td>E</td>
<td>334.8</td>
<td>359.6</td>
<td>0.31</td>
<td>4.5</td>
<td>6:01</td>
<td>0*7D</td>
</tr>
<tr>
<td>6753.4195</td>
<td>N</td>
<td>02106.3449</td>
<td>E</td>
<td>335.3</td>
<td>359.6</td>
<td>0.17</td>
<td>0.4</td>
<td>5:01</td>
<td>0*7A</td>
</tr>
<tr>
<td>6753.4200</td>
<td>N</td>
<td>02106.3451</td>
<td>E</td>
<td>334.5</td>
<td>359.6</td>
<td>0.49</td>
<td>-0.7</td>
<td>6:01</td>
<td>0*52</td>
</tr>
<tr>
<td>6753.4199</td>
<td>N</td>
<td>02106.3455</td>
<td>E</td>
<td>335</td>
<td>359.6</td>
<td>0.17</td>
<td>0.5</td>
<td>5:01</td>
<td>0*77</td>
</tr>
<tr>
<td>6753.4200</td>
<td>N</td>
<td>02106.3467</td>
<td>E</td>
<td>335.6</td>
<td>359.6</td>
<td>0.18</td>
<td>0.5</td>
<td>5:01</td>
<td>0*72</td>
</tr>
</tbody>
</table>

For simplicity and understanding, the data is represented in 2 sections. The columns highlighted using different colors represents different measured values. Green columns gives the height (m) above reference, yellow represents the horizontal speed component in knots, blue represents the vertical speed component in m/s and light orange represents the direction in degrees. The data obtained from ETAG can be converted to Excel format for further analysis and understanding the wind profile.
Figure 16 represents the achieved height during testing no.3. The horizontal axis represents the test time. Two cases marked in the figure represent two tests. Both the test was done near the Esrange wind tower.

Case (a): maximum height achieved was 62.5 m.
Case (b): maximum height achieved was 66.8 m. Sharp fall in case (b) was due to balloon burst at that height.

The Esrange wind tower is measuring data at 6 different locations: 10m, 25m, 45m, 65m, 85m, and 100m above the ground level (329.8m). The speed of wind and directions are easily obtained from EGIS website [41]. The value obtained from wind tower will be compared with the data obtained from present tests. The following figures show the data obtained from the wind tower which gives the wind data and direction for 6 altitudes.

Figure 17 Esrange wind tower data at 10m [41]
An Alternative Approach to Measure Low Level Winds at Esrange

Figure 18: Esrange wind tower data at 25m [41]

Figure 19: Esrange wind tower data at 45m [41]

Figure 20: Esrange wind tower data at 65m [41]
Figures 17-22 are showing the data obtained from EGIS. The EGIS website gives wind speed and direction at 6 different altitudes. It shows the wind rose and the wind speed variation vs. time. Level gives the height and UTC is the test time and also results were shown for 10 minutes duration.

A wind rose gives a very brief view how wind speed and direction are normally distributed at a particular location. Generally it is presented in a circular format (like a compass). It shows the frequency of wind blowing from particular direction at that time. The frequency of wind blows from a particular direction per unit time is related to the length of each ‘spoke’ around the circle. Frequencies of wind are increasing from a zero value at the center to higher values at the outer circles. Each spoke is broken down into separate frequency categories. The wind rose uses 16 cardinal directions (such as N, NE, etc). [42]

Wind is usually characterized by its direction, speed and gustiness. Average wind data are determined for a period between 10 to 60 min. Averaging periods less than a few minutes do not sufficiently smooth the usually occurring natural turbulent fluctuation of wind. Wind speed estimation is based on the effect of the wind on movable object. The response of wind measurement system is very important to determine peak gust and duration. Slow responding systems smear out the extremes and measure long smooth gusts whereas the fast responding
systems may indicate sharp wave front gust with a short duration. Wind speed over a rough terrain increases with height. A standard height of 10m above open terrain is specified for the exposure of wind instrument. The following table shows the wind speed equivalent for the standard height of a 10 m above the open flat ground. [43]

<table>
<thead>
<tr>
<th>Beaufort scale number and description</th>
<th>Wind speed equivalent at a standard height of 10 m above open flat ground</th>
<th>Specifications for estimating speed over land</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Calm</td>
<td>&lt; 1 0 – 0.2 1 &lt; 1</td>
<td>Calm; smoke rises vertically</td>
</tr>
<tr>
<td>1 Light air</td>
<td>1 – 3 0.3 – 1.5 1 – 5 1 – 3</td>
<td>Direction of wind shown by smoke-drift but not by wind vanes</td>
</tr>
<tr>
<td>2 Light breeze</td>
<td>4 – 6 1.6 – 3.3 6 – 11 4 – 7</td>
<td>Wind felt on face; leaves rustle; ordinary vanes moved by wind</td>
</tr>
<tr>
<td>3 Gentle breeze</td>
<td>7 – 10 3.4 – 5.4 12 – 19 8 – 12</td>
<td>Leaves and small twigs in constant motion; wind extends light flag</td>
</tr>
<tr>
<td>4 Moderate breeze</td>
<td>11 – 16 5.5 – 7.9 20 – 28 13 – 18</td>
<td>Raises dust; and loose paper; small branches are moved</td>
</tr>
<tr>
<td>5 Fresh breeze</td>
<td>17 – 21 8.0 – 10.7 29 – 38 19 – 24</td>
<td>Small trees in leaf begin to sway; crested wavelets form on inland waters</td>
</tr>
<tr>
<td>6 Strong breeze</td>
<td>22 – 27 10.8 – 13.8 39 – 49 25 – 31</td>
<td>Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty</td>
</tr>
<tr>
<td>7 Near gale</td>
<td>28 – 33 13.9 – 17.1 50 – 61 32 – 38</td>
<td>Whole trees in motion; Inconvenience felt when walking against the wind</td>
</tr>
<tr>
<td>8 Gale</td>
<td>34 – 40 17.2 – 20.7 62 – 74 39 – 46</td>
<td>Breaks twigs off trees; generally impedes progress</td>
</tr>
<tr>
<td>9 Strong gale</td>
<td>41 – 47 20.8 – 24.4 75 – 88 47 – 54</td>
<td>Slight structural damage occurs (chimney-pots and slates removed)</td>
</tr>
<tr>
<td>10 Storm</td>
<td>48 – 55 24.5 – 28.4 89 – 102 55 – 63</td>
<td>Seldom experienced inland; trees uprooted; considerable structural damage occurs</td>
</tr>
<tr>
<td>11 Violent storm</td>
<td>56 – 63 28.5 – 32.6 103 – 117 64 – 72</td>
<td>Very rarely experienced; accompanied by widespread damage</td>
</tr>
<tr>
<td>12 Hurricane</td>
<td>64 and over 32.7 and over 118 and over 73 and over</td>
<td></td>
</tr>
</tbody>
</table>
The data obtained from ETAG during prototype testing were compared with the Esrange wind tower data. Figure 23 shows the comparison between the data obtained from ETAG and wind tower data for 3 different altitudes. It can be observed from the figure that the wind speed data from ETAG is showing huge difference. Such as for 25 m height, while the balloon is going up, the wind speed value was measured to be 5.2 m/s and the corresponding wind tower value was approximately 2.7 m/s. The data for balloon coming down will be deleted as only the ascending values will be used for the analysis.

**Case (a):**

![Figure 23 Wind speed vs. height comparison for case (a)](image)

**Case (b):**

![Figure 24 Wind speed vs. height comparison for case (b)](image)
Figure 24 shows the similar comparison between the data obtained from ETAG and wind tower data for 4 different altitudes. Here the similar trend was observed that the ETAG is giving higher values of wind speed. Therefore it is necessary to further testing of the prototype to study the feasibility of ETAG for measuring low level wind.

Further Testing:
The balloon was launched for the balloon launch pad located at Esrange. This balloon pad is located approximately 300m away from the Esrange wind tower. The balloon was launched with a PiBall (Pilot Balloon) to check the accuracy of measurement and also comparing data with the wind tower. The maximum height achieved was approximately 125 m and the height with time is shown in the following fig.25. Different fishing lines have been tested and finally a suitable line was selected.

![Figure 25 Prototype further testing (Height vs. Time)]

From the dotted region in fig. 25, it is clear that to bring the balloon down to ground level using ordinary fishing reel and rod assembly was very difficult and hard task.

One of the simple ways to determine wind data above the surface is with a pilot balloon. A pilot balloon, filled with helium, rises at a known speed, but drifts freely with the wind. A theodolite is a small telescope used to track the pilot balloon. The balloon’s vertical and horizontal angles are measured in every minute. The vertical angle gives the height and horizontal angle gives the direction. Generally wind speed and direction are computed at specific intervals, such as 300 ft for our testing. [44]
Table 2 shows the comparison of ETAG data with data obtained from PiBall test. The table shows that ETAG is giving higher wind speed for 46m altitude. So again the wind data from ETAG rise question about its practicability to measure low level wind using it.

<table>
<thead>
<tr>
<th>Height</th>
<th>PiBall : wind Speed [knots]</th>
<th>PiBall wind direction [deg]</th>
<th>ETAG Wind speed [knots]</th>
<th>ETAG wind direction [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>46m</td>
<td>9.8</td>
<td>160.1</td>
<td>12.08</td>
<td>166</td>
</tr>
</tbody>
</table>

The wind data again compared with wind tower data is shown in the following fig.26. Similar trend of wind speed was observed and ETAG is always giving higher wind speed value. When the balloon is going upward, it is giving wind speed values between 5m/s to 8 m/s. These values are higher than wind tower value in order of 1m/s to 3.5 m/s. The deviation is not consistent. In general, the prototype testing result was not satisfactory. So without additional testing, it is difficult to conclude that ETAG can be used to measure low level wind. Also the system design is critical as the wind condition is changing with time. Further ETAG data analysis is necessary to give a conclusion.

![Figure 26 Wind speed comparison vs. height (further testing)](image-url)
5.3 Wind Profile

As discussed in prototype testing section that several tests were performed up to 100 m and above. The comparison of data with Esrange wind tower has been studied. But the data obtained from ETAG was showing higher wind speed and deviation from the wind tower data. So there is a need to analysis some more data from ETAG. Otherwise satisfactory conclusion about the feasibility of ETAG can’t be drawn.

As Esrange is using ETAG in every meteorological balloon launched this year, there are data available from previous flights. Seventeen such balloon flights have been selected and the wind data has been analyzed.

The following sections include the flight results of previous 17 meteorological balloons launched from Esrange and comparison with the wind tower data at that time. Vertical wind profiles are calculated and shown for each flight. The y axis in the wind profile gives the height above the ground level in meter and x axis gives the wind speed and wind direction corresponding to the height. The wind profiles will be used to see the wind variation with increasing altitude and general trend at Esrange. The flight data is also analyzed to check whether the results we are getting from ETAG, can be comparable to wind tower.

These analyzed data will also give us a completely view about the wind data measured using ETAG. Also to find out the testing error and uncertainty, these data will be valuable. But as seen from the results, the ETAG data gives wind speed values higher than wind tower results.

Raw data from ETAG:

It was shown in the prototype testing chapter that the data obtained from ETAG directly gives the wind speed in Knots and wind directions in degrees. The following figures show the wind speed [m/s] and direction [degrees] vs. altitude up to 600 m for unprocessed data from ETAG. These meteorological balloons were launched before rocket launch. The measured wind speed up to 600 m height can be used to understand the 60% of the wind effect. That’s why all the figures are plotted up to 600 m altitude.

From the following figures 27-30 and Appendix F, it is clear that the unprocessed data from ETAG is not suitable for wind direction and wind measurement. The measured wind speed and direction is not precise and also showing variation with the wind tower data. The unprocessed data from ETAG was compared with wind speed and direction from wind tower and still the ETAG data is giving higher values. Wind profile figures for other balloons using the raw data from ETAG are shown in Appendix F.
An Alternative Approach to Measure Low Level Winds at Esrange

Figure 27 Wind profile (Raw data from ETAG-T44B2)

Figure 28 Wind profile (Raw data from ETAG-T45B3)

Figure 29 Wind profile (Raw data from ETAG-APR1)

Figure 30 Wind profile (Raw data from ETAG-M1)
There is a need to identify a proper method to find correct and reliable wind speed. Also ETAG feasibility for measuring low level wind precisely needs to be checked. As mentioned earlier, Esrange is using wind weighting software (WWS) for measuring wind before every rocket launch and determine the azimuth and elevation for each launch. The measurement process can be easily described using the following fig. 31. In the fig. 31, it is shown that wind speed up to 100m height is covered by Esrange wind tower as it is precisely measuring wind speed and direction and calibrated every year. The ground level height starts from 329.8 m and first 100m wind speed and direction value is measured by wind tower. Latitude, longitude and time difference values from ETAG are used for wind measurement. At 125 m height, first point is selected. Once the first point is selected then for different layers (25m or 50 m gap), wind speed and direction is measured. The first point becomes the reference point and wind speed and direction are measured relative to reference point. Absolute velocity is measured from north and east velocity component and direction. Using this method followed by wind weighting software (WWS), the wind speed and wind direction are again calculated for up to 700 m height and the result is shown in the following figures 32-35 and Appendix F. Also the new result was compared with the raw data and wind tower result for better understanding and finding the drawbacks related to wind measurement using ETAG.

Figure 31 Wind measurement at different layers using wind weighting software
An Alternative Approach to Measure Low Level Winds at Esrange

Figure 32 Wind profile (ETAG data from WWS- T44B2)

Figure 33 Wind profile (ETAG data from WWS- T45B3)

Figure 34 Wind profile (ETAG data from WWS- APR1)

Figure 35 Wind profile (ETAG data from WWS- M1)
The wind speed and wind direction obtained from wind weighting software were shown in figures 32-35. The wind speed is showing zigzag pattern and similar to those obtained from unprocessed ETAG data. But wind direction is showing better trend for some cases. The measured wind speed values are varying from approximately 1 m/s to 8 m/s. The maximum wind speed was observed within the range between 400 m and 600 m. The following paragraph briefly explains the figures 32-35.

ETAG data from balloon launched in four different days has been selected for the analysis purpose. The wind speed range and direction varies for different days. These balloons are launched prior to any rocket launch.

- On 7th February 2008, four meteorological balloons were launched. Figure 32 shows that the wind speed was approximately 1.8 m/s near the ground level (above 10 m from ground). It starts increasing up to 450 m where the maximum wind speed value of approximately 8.1 m/s was observed. From 425 m to 600 m, wind speed is fluctuating and a wind shift was observed. Gentle to moderate wind was blowing from NW, NNW direction. Another 3 balloons (Appendix F) were launched at the same day. Maximum wind speed was observed within the range 6-8 m/s at the height between 400 m and 650 m. Also wind shift was observed within the altitude range. The wind direction changes from NW to NE within 4 hours time duration.

- On 21st February 2008, four meteorological balloons were launched. Figure 33 Wind profile (ETAG data from WWS- T45B3) shows that the wind speed was approximately 1 m/s near the ground level (above 10 m from ground). The wind speed is varying up to 500 m where the maximum wind speed value of approximately 6 m/s was observed. From 330 m to 550 m, wind speed is fluctuating and wind shifting was observed. Gentle to moderate wind was blowing and direction was changing from SSW to NW during the observation period. Another 3 balloons (Appendix F) were launched at the same day. Maximum wind speed was observed within the range 5-6 m/s at the height between 400 m and 550 m. Also wind shift was observed within the altitude range. The wind direction changes from SSW to NE within 2 hours time duration and was shifting frequently. This variation suggests that there may be some measurement errors which need to be identified.

- On 1st April 2008, five meteorological balloons were launched to measure wind speed and direction. Figure 34 shows that the wind speed was approximately 2 m/s near the ground level (above 10 m from ground). The wind speed is varying up to 500 m where the maximum wind speed value of approximately 6 m/s was observed. From 330 m to 650 m, wind speed is fluctuating and wind shifting was observed. Gentle to moderate wind was blowing and direction was changing from WNW to ENE during the observation period. Another 4 balloons (Appendix F) were launched at the same day. Maximum wind speed was observed within the range 5-8 m/s at the height between 350 m and 600 m. Also wind shift was observed within the altitude range.
The wind direction changes from WNW to ENE within 4 hours time duration and was shifting frequently.

- Final four meteorological balloons were launched on 1st May, 2008. Figure 35 shows that the wind speed was approximately 0.5 m/s near the ground level (above 10 m from ground). The wind speed is varying up to 700 m where the maximum wind speed value of approximately 7 m/s was observed. From 330 m to 700 m, wind speed is fluctuating and wind shift was observed. Light to moderate wind was blowing and direction was changing from SSW to WNW during the observation period. Another 3 balloons (Appendix F) were launched at the same day. Maximum wind speed was observed within the range 5-8 m/s at the height between 350m and 550m. Also wind shift was observed within the altitude range. The wind direction changes from SSW to WSW within 4 hours time duration and was shifting frequently.

Wind speed values from the weighting software are compared with the raw data from ETAG and are plotted in the following figure 36 and Appendix F. The purpose of this comparison study is to check the variation between the raw data from ETAG and processed data from wind weighting software. The processed data from wind weighting software should be the average value of the raw data from ETAG for a particular altitude layer. Figure 36 show that the wind speed value from wind weighting software is a mean value of unprocessed data for a certain layer. Also some of the values have been filtered from the unprocessed data to get the smooth curve.
An Alternative Approach to Measure Low Level Winds at Esrange

Figure 36 Comparison of wind data (raw data vs. data from WWS-T44)
Wind speed values from wind weighting software are compared with the wind tower data. As wind speed is measured in 6 different altitudes from wind tower, the following figures show the comparison of values for the approximate measured altitudes. The wind speed values from wind weighting software (processed data from ETAG) are represented by altitude which is near to Esrange wind tower measurement altitude. X axis represent the altitude in m and Y axis represent the wind speed in m/s.

From the above figure 37 and Appendix F, it can be observed that the values from the wind weighting software are always giving higher values of wind speed compared to Esrange wind tower. Similar wind speed trend was observed from the prototype testing. There are some cases where both the values from wind weighting software and wind tower are similar but in general it is varying. The Esrange wind tower is calibrated and tested every year and the wind speed and direction values have already been verified using various standard testing procedure.
So it can be concluded from the above data analysis that the ETAG value is not suitable for low level wind measurement. Major modifications in ETAG software and also in data acquisition methods are required for measuring the wind speed and direction. Also without further testing, it is impossible to build the final system. Therefore it is recommended to address the reasons for the deviation first. The system can be built in small scale after this modification using the system parameters listed in Appendix D. The design parameters (line, motorized fishing reel, etc) are given in the appendix to build the system. The system need to be tested for a long duration and compared with other wind measurement method. Therefore the feasibility studies of the present thesis suggest not building the system and performing additional testing before dealing with the associated problems.

To obtain high quality wind data from measurement of balloon motions, three factors are considered: (i) the response of the wind sensors to wind, (ii) the accuracy of the tracking system, and (iii) the aerodynamically induced motions of the sensors for measuring the wind. Aerodynamic lift forces normal to the velocity vector of the air is the source to create the induced balloon motions. The errors in wind measurement are due to random or self induced balloon motion. The thermodynamic properties of air and the physical properties of balloon are the factors used to control the induced sensor motion. So filtering of wind data is necessary. To filter wind data, knowledge of aerodynamic lift and drag force coefficient is required. If fine scale variations are not important, the effects of self-induced motions are removed by filtering. There are some approaches are possible to apply for reduction of errors in wind measurement if fine scale fluctuations of wind are important. One way is to reduce the ascending speed of the balloon. It can be done either by increasing its weight or its drag. But there are certain disadvantages associated with this method, such as it would take longer time for a given sounding and occurrence of low elevation angles, which will result large tracking errors. Also the error due to inertial lag will increase if the ascending rate is decreased by increasing balloon mass. The magnitude of self-induced motion for balloon is directly proportional to the terminal velocity. \[45, 46\]

**5.4 Reasons and Recommendations**

**Possible Reasons for Deviation:**
As ETAG values are giving results which are varying from wind tower and the measurement is not precise for low altitude range, there is a need to identify the possible reasons for the deviation and drawback of the system. The following reasons have been identified through present testing and analysis and these findings will improve the system potential to measure low level wind speed.

1. **Balloon Launch from Balloon pad**
   Most of the balloons are launched from balloon pad which is approximately 300m away from wind tower. This distance between measurement locations may induce errors while comparing the wind data.
2. Data sending rate from ETAG
   ETAG is sending data once per second. It is impossible to get good approximation for
   wind speed at a certain altitude for such data sending rate. For example, the average
   ascending speed of balloon is 5m/s. If it is required to measure wind speed at 400m
   altitude, then only one or two values can be obtained for that altitude. Taking the
   average of two values is not proper way to find a speed. So this induces error to the
   measurement.

3. Thick layer for wind measurement
   In general wind measurement is done for a thick altitude layer between 50m and
   200m. As the present thesis tried to compare wind speed values for thin layer of 10m
   to 20m, the measured values are not accurate way of presenting wind profile. Again
   only reliable source to compare wind speed value up to 100m was the data from wind
   tower and the measured altitude difference is 20m. So again it may introduce some
   errors in measurement.

4. Data Telemetry
   The data received from the ETAG need to be verified also by using other methods. It
   is necessary to have other methods like radar, tracking to verify the data received by
   ground station.

5. GPS error
   GPS errors can introduce very small errors in measurement. As ETAG is a standard
   GPS, the error source need to be identified. If the balloon is launched from the
   balloon pad then it is an open field where as near the wind tower, there are some
   obstacles which may create multipath effect.

6. Gust detection
   Gusts are the sudden increases in the strength of the wind. Gusts can last several
   seconds or more. So it needs to be identified that the measured wind speed at certain
   altitude is not gust. Meteorological standards need to be checked for gust detection.
   To determine peak gusts accurately, it is desirable to sample the filtered wind signal
   every 0.25 s (frequency 4 Hz).

**Recommendation and modification in the design and Analysis:**

i. The balloon should be launched from a position very close to the wind tower. Then
   comparing the wind data may give better results.

ii. Reprogram ETAG
    ETAG need to be reprogrammed for sending faster data. More data will give the
    possibility to have better prediction of wind speed at a certain altitude.

iii. Tracking using radar or other methods
Radar reflector was using before to measure wind speed at Esrange. ETAG and beacon system need to be checked and the data need to be compared with the data obtained from radar.

iv. Thick layers
This is discussed earlier that the measurement should be done for thick layer between 50 m to 200 m.

v. ETAG should be checked again vs. radiosonde
This is already done at Esrange. This comparison study will be valuable for further analysis.

vi. Two ETAG should be used
Two ETAG operating at different frequencies can used to check the wind data.

vii. Comparison with free moving balloon
One free balloon and balloon with line needed to be launched at the same time to check the wind data.

viii. Lighter volume balloon
Lighter volume balloon can give more values for a specific altitude range. But then ascent speed will decrease due to the lower lifting force of the balloon.
Chapter 6

Conclusion and Future Work

This thesis is an attempt to find alternative approach to measure low level wind which can be useful for Esrange preflight tests. Based on the initial literature review and theoretical study, a mechanical system was proposed with major system parameters such as line, motorized fishing reel etc. A prototype was tested and the result was compared up to 100m with an existing wind tower. Although the prototype test was successful up to 150 m, the result obtained from the test was unsatisfactory while comparing with wind tower data. These differences in wind speed value lead the thesis work to further investigate data from ETAG. The data from seventeen meteorological balloons launched from Esrange are presented in the thesis. The wind profile and wind direction were also shown for various altitude and finally the data was compared again with the wind tower value. But deviation of wind speed value was observed. As the initial feasibility studies showed variation and drawbacks, the system was not made for further testing. The thesis finally concludes with defining some possible reasons and some solutions to modify the ETAG, mechanical system and measurement procedure.

There is scope of continuing this work further by modifying the ETAG and several parameters. With the help of the SMwind Excel spreadsheet, further analysis is possible. Once the possible reasons mentioned in this thesis are addressed properly, the system can be built in small scale and tested in future. The system once built will give opportunity to further explore various research possibilities.

Further research is needed in both the immediate practical problem related fine scale wind measurement and in understanding the physical mechanisms producing the motions. Also boundary layer wind model intended for engineering purposes can be studied and developed. The main input data needed for such model are the wind speed and direction at a standard level, the temperature difference between the layer and roughness length. Data handling procedure need to be refined to improve the quality of measured wind data for further analysis. Also the feasibility of turbulence measurement for low altitude can be done using the proposed system. Thus the present proposed wind measurement system can be used for further meteorological research. [46, 47]
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42. Wind Rose Data, National Water and Climate Center, USA, http://www.wcc.nrcs.usda.gov/climate/windrose.html
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50. Abu Garcia, website link: http://www.abugarcia.se/
52. Elec-tra-mate , website link: http://www.elec-tra-mate.com/phychal.html
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Appendix A: ETAG Specification

Figure 38 ETAG –Esrange Throw Away GPS [37]

Technical Specification: (Transmitter Unit) [37]

- RF frequency: 173.225 MHz
- Modulation: FM
- RF deviation: +/- 2.5 kHz
- RF output power: 10 dBm
- Data speed: 1200 bit/sec
- Data type: Ascii
- NMEA sentences: ZDA,GGA,RMC
- Update speed: 0.5 Hz

General Specification [36]

<table>
<thead>
<tr>
<th>General</th>
<th>L1,C/A Code, SPS</th>
<th>12 channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update rate</td>
<td>1 fix/s (user configurable)</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>Position: 3m (CEP), 8m (2dRMC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Velocity: 2 m/s RMS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time: TBD</td>
<td></td>
</tr>
<tr>
<td>TTFF</td>
<td>Cold Start: 40 s typ.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warm Start: 33 s typ.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tracking: 4 s typ.</td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Acquisition (cold): -139 dBm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Navigation: -154 dBm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tracking: -155 dBm</td>
<td></td>
</tr>
<tr>
<td>Power drain</td>
<td>Navigation 1 fix/s: 100mW typ.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stand-by state: 15mW typ.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Back Up/Sleep state: 60µW typ.</td>
<td></td>
</tr>
</tbody>
</table>
An Alternative Approach to Measure Low Level Winds at Esrange

<table>
<thead>
<tr>
<th>Operating Voltage: Main supply: RF supply:</th>
<th>+2.7V..3.3V +2.7V..3.3V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature: Serial port: GPIO, number of: Peripherals: SBAS: Chip set: Memory:</td>
<td>-40C..+85C 2 17 (shared functionality) SPI, MMC, Timer, PM WAAS/Egnos µNav µN8021+µN2110 8Mbit flash</td>
</tr>
</tbody>
</table>

Other

Receiving Equipment for ETAG [37]

- Ground Station
  - Antennas
    - 2 x Yagies 10 dB circular connected
  - Filter and Pre-amplifier
    - Cavity bandpass filter, 173.225 MHz, +/- 300 kHz (3 dB)
    - Pre-amplifier, 173.225 MHz, 40 dB
  - Receiver
    - Yaesu FRG-9600
    - NBFM, rebuilt with filter and serial rs232 data output

![Diagram of ETAG ground receiving system](image)

**Figure 39 ETAG ground receiving system [37]**
Appendix B: Esrange Wind Tower Sensor

WindObserver II - ULTRASONIC WIND SENSOR

The WindObserver II has all of the performance features of the WindSonic plus increased speed range, an optional de-icing system extending the operational temperature range, stainless steel construction, IP66 enclosure, sonic temperature output and averaging (1-3600s). The WindObserver II has a proven record in airport, offshore, marine and naval applications. The WindObserver II has been rigorously tested to a number of international standards. [50]

Technical Specifications [48]:

<table>
<thead>
<tr>
<th>Dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>400mm x 210mm</td>
</tr>
<tr>
<td>Weight</td>
<td>1.5kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>1Hz, 4Hz, 10Hz</td>
</tr>
<tr>
<td>Parameters</td>
<td>UV, Polar, NIMRA, Tunnel</td>
</tr>
<tr>
<td>Units</td>
<td>m/s, Knots, MPH, KPH</td>
</tr>
<tr>
<td>Averaging</td>
<td>Flexible 1-3600 seconds</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>0 - 65 m/s (0 - 145mph)</td>
</tr>
<tr>
<td>Starting Threshold</td>
<td>0.01 m/s</td>
</tr>
<tr>
<td>Accuracy</td>
<td>2%</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.01 m/s</td>
</tr>
<tr>
<td>Offset</td>
<td>± 0.01 m/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>0 - 359°</td>
</tr>
<tr>
<td>Dead Band Direction</td>
<td>None</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 2°</td>
</tr>
<tr>
<td>Resolution</td>
<td>1°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sonic Temperature</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>-40°C to +70°C (refer to user manual)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Digital Output</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>RS422, full duplex</td>
</tr>
<tr>
<td>Baud Rate</td>
<td>1200 2400 4800 9600 19200 38400</td>
</tr>
<tr>
<td>Format</td>
<td>8 data,Odd,even or no parity</td>
</tr>
<tr>
<td>Anemometer Status</td>
<td>Supplied as part of standard message</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analogue Output - Optional</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>3 (speed, direction, status or sonic temp)</td>
</tr>
<tr>
<td>Scale</td>
<td>Multiples of ±10 m/s up to 70 m/s</td>
</tr>
<tr>
<td>Type</td>
<td>± 3.5V, 0.5V or 4 - 20mA</td>
</tr>
<tr>
<td>V Output Resistance</td>
<td>60 Ohms</td>
</tr>
<tr>
<td>4 - 20mA Loading</td>
<td>10 - 300 Ohms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>External Construction</td>
<td>Stainless Steel 316</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Protection</td>
<td>IP66 (NEMA4X)</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-55°C to +70°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>5% to 100% RH</td>
</tr>
<tr>
<td>Precipitation</td>
<td>300mm/hr</td>
</tr>
<tr>
<td>EMC</td>
<td>EN 61000-6-2 : 2001</td>
</tr>
<tr>
<td>EN 61000-6-3 : 2001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MISC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards</td>
<td>Traceable to NAMAS standards</td>
</tr>
<tr>
<td>Site Calibration</td>
<td>None Required</td>
</tr>
<tr>
<td>Integrity Check Unit (Zero Wind)</td>
<td>supplied as optional extra</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Requirement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemometer only</td>
<td>9-30 V DC (40mA @ 12 V DC)</td>
</tr>
<tr>
<td>Heating Option</td>
<td>3A @24V AC or DC</td>
</tr>
</tbody>
</table>
**Appendix C: Balloon Flight Analysis**

The following theoretical analysis was done using the SMWind Excel program.

<table>
<thead>
<tr>
<th>Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braided Nylon Twine 1 mm diameter</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test No</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balloon Inflation Diameter (ft)</td>
<td>4.16</td>
</tr>
<tr>
<td>Balloon Volume (ft³)</td>
<td>37.69464</td>
</tr>
<tr>
<td>Mass of Balloon (gm)</td>
<td>100</td>
</tr>
</tbody>
</table>

| Lift of Helium in standard air (N/ft³) | 0.311 |
| weight of Etag gm | 150 | 1.4715 |
| Free lift (N) Fu | 9.270534 |

<table>
<thead>
<tr>
<th>String weight Ws (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ (N/ft)</td>
</tr>
<tr>
<td>L (ft)</td>
</tr>
</tbody>
</table>

| Drag (N) | 6.215771 |
|------------------|
| Cd | 0.5 |
| Density (kg/m³) | 1.23 |
| air speed (m/s) | 4 |
| Area (m²) | 1.263368 |

<table>
<thead>
<tr>
<th>Tension (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Fu -Ws</td>
</tr>
<tr>
<td>Horizontal Fd</td>
</tr>
<tr>
<td>Total tension (N)</td>
</tr>
</tbody>
</table>

Line: "Braided" Nylon Seine Twine [49]

**Specification:**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>#9</td>
<td>2220</td>
<td>80</td>
<td>.042&quot;</td>
<td>16109</td>
<td>16309</td>
<td>16409</td>
</tr>
<tr>
<td>#12</td>
<td>1600</td>
<td>95</td>
<td>.046&quot;</td>
<td>16112</td>
<td>16312</td>
<td>16412</td>
</tr>
<tr>
<td>#15</td>
<td>1300</td>
<td>120</td>
<td>.051&quot;</td>
<td>16115</td>
<td>16315</td>
<td>16415</td>
</tr>
</tbody>
</table>
Now for the same line specification, the following table shows the tension with varying length of the line and wind speed. This table shows that the tension increases with increasing wind speed.

<table>
<thead>
<tr>
<th>Length of the line (meter)</th>
<th>Wind Speed (m/s)</th>
<th>Tension (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>4</td>
<td>8.149499</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>14.94564</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>25.41557</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>39.20446</td>
</tr>
<tr>
<td>1000</td>
<td>4</td>
<td>6.765172</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>14.23817</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>25.00609</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>38.94025</td>
</tr>
</tbody>
</table>

The same process is repeated for different lines including the fishing lines with diameter less than 1 mm. Fishing lines with diameter less than 1 mm were selected for testing purpose due to the spool line capacity limitations. Also fishing line is adding less weight to the system than the braided nylon twine.
Appendix D: Line and Motorized Reel Selection

The following lines and motorized reel have been chosen for the further testing purpose in future and may be used for building the small scale wind measurement system. If the testing give satisfactory result then the similar higher capacity motorized reel need to be purchased.

Line: Preferred diameter: 0.3 mm and above, but less than 0.8 mm. [50]
Electric Fishing Reel

Model 450-PTH
Recognizing the need for a lightweight power driven electric spinning reel, the Model 450-PTH was created to fill this void. The same engineering knows how and fishing experience used in developing offshore fishing products has now been applied for fresh water use. From the leaders in electric fishing reel drives comes the ultimate in power drives for fresh water fishing reels. Unlike other electric spinning reels the 450-PTH has the power to easily overcome largemouth bass, smallmouth bass, brim, crappie, and other fresh water species without the need to "assist" the motor by cranking. [51, 52]

The "All New" Model 450-PTH has been designed to power the popular Penn® 450SSG and 550SSG Spinfisher Spinning Reels. Like other popular Elec-Tra-Mate® fishing reel models, the "New" 450-PTH is easily attached to the side of a standard Penn Reel® in literally minutes and is available with or without the reel. [51, 52]
The weight is only 18oz. This model is also available with switch cord only for attachment to specialty switches usable by physically challenged anglers. Choose the ever popular 6 ft. coiled cord and plug for use with the optional 12 Volt DC Portable Battery Pack for fishing anywhere, anytime, or a 10 ft. cord with solid copper alligator clips for use on your own battery. [51, 52]

**Model 1412-G**
The Model 1412 is engineered to be the quietest and most powerful 12 Volt DC drive ever put on a fishing reel. Because of this drive’s extreme power, it is only available to fit Penn 12/0 and 14/0 Senator Reels. It is manufactured from the finest corrosion resistant materials available such as polished stainless steel and anodized aircraft aluminum. Standard equipment includes 10 ft power cord, 30 amp marine plug, and 3-position toggle switch. Battery ring terminals and solid copper alligator clips are also available. [51, 52]
Open-Bail Spinning Reel

With a spin-casting reel, a mechanical pickup is used to retrieve the line and an anti-reverse lever prevents the crank handle from rotating while a fish is pulling line from the spool. And because the line doesn't have to pull against a rotating spool, like it does with a bait-casting reel, you can use much lighter lures with a spin-casting reel. Fixed-spool reels are cast by opening the bail, grasping the line with the forefinger and then using a backward snap of the rod followed by a forward cast, releasing the line with the forefinger at the same time. On the retrieve, the large rotating wire cage or bail (either manually or trigger-operated) serves as the line pickup, restoring the line to its original position on the spool. Open-Bail reels are traditionally mounted below the rod. And they're really pretty simple to use. [53]
Appendix E: Esrange SMWind Excel Program

SMWind Excel Program

Prepared by: Sheikh Zahidul Islam, Graduate Student, SpaceMaster
Department of Space Science, Luleå University of Technology, Kiruna, Sweden

Contents of this Excel Spreadsheet:
1. Title page
2. Data from ETAG
3. Reynolds Number and Drag Coefficient
4. Drag coefficient vs. Reynolds number plot
5. Balloon Flight Analysis
6. Data from Wind Tower
7. Wind data from wind weighting software
8. Wind Profile
9. Wind Direction
10. Wind data comparison with Wind Tower
11. Summary Report

This spreadsheet is created for analysis of balloon flight and further understanding the wind profile at Esrange. For more information please contact my supervisor:

Olle Persson
Project Manager, Sounding Rocket and Balloon,
Aerospace Services Division,
Esrange Space Center, Swedish Space Corporation
P.O. Box. 802, SE- 98128, Kiruna Sweden
E-mail: olle.persson@esrange.ssc.se
Phone: +46 960 722 05
An Alternative Approach to Measure Low Level Winds at Esrange

Data From ETAG

<table>
<thead>
<tr>
<th>TIME</th>
<th>SOURCE</th>
<th>LAT</th>
<th>ALT (m)</th>
<th>HSPD (Knots)</th>
<th>VSPD (Knots)</th>
<th>STATUS OF DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:42:36 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>322.9</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:42:36 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>322.9</td>
<td>0.031</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:41:30 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>323.1</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:41:30 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>323.1</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:40:49 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>323.1</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:40:49 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>323.1</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:39:59 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>323.1</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
<tr>
<td>8:39:59 AM</td>
<td>SPHEREPOS</td>
<td>70°08' 00&quot;</td>
<td>323.1</td>
<td>0.041</td>
<td>0.031</td>
<td>07/01</td>
</tr>
</tbody>
</table>

Reynolds Number and Drag Coefficient

\[ \text{Re} = \frac{pD}{\mu} \]
\[ \text{CD} = \frac{QD}{\pi A} \]

where:
- \( p \) is the mean fluid velocity in (ft units/ms)
- \( D \) is the diameter (m)
- \( \mu \) is the dynamic viscosity of the fluid (Pa s or N s/m²)
- \( \nu \) is the kinematic viscosity (m²/s or ft²/s)
- \( \rho \) is the fluid density (lbm/ft³ or kg/m³)
- \( A \) is the pipe cross-sectional area (m²)

Drag coefficient \( C_D \) is a function of Re which is very important concept for the present thesis. \( C_D \) values are calculated using the following equations:

\[ C_D = 0.5 + 24(Re^{0.101}) \quad \text{for Re} > 4.5 \times 10^4 \]

Numerical study of open-atmospheric balloon dynamics (Physics of Fluids 5,[16])

An Alternative Approach to Measure Low Level Winds at Esrange
An Alternative Approach to Measure Low Level Winds at Esrange
Appendix F: Wind Profile

Raw data from ETAG:

[Graphs showing wind direction and speed at various heights for different days]
ETAG data from Wind Weighting Software:
An Alternative Approach to Measure Low Level Winds at Esrange
Comparison of wind data:
An Alternative Approach to Measure Low Level Winds at Esrange
Wind data from ETAG compared with the Wind tower data:
An Alternative Approach to Measure Low Level Winds at Esrange