97-1435 A NEW AIRSHIP GROUND HANDLING SYSTEM THAT WORKS

by
Simon Christoforato*, DERA, U.K. MOD
Robert L. Ashford*, Consultant, TCOM,L.P.

Abstract

The Defence Evaluation and Research Agency of the UK Ministry of Defence contracted TCOM to modify a 71M® aerostat mooring system to demonstrate its capability for improved airship ground handling.

Changes were made to both the airship and the mooring system to allow the airship to dock onto the mast. These included extending the airship nose line and adding a down haul line at the rear of the gondola; the mooring system mast was changed and an extension was added to the rotary boom.

During the week of 21 October 1996, the masting trials were undertaken at the TCOM Manufacturing and Flight Test facility in Weeksville, North Carolina, USA. On Thursday evening, 24 October 1996, the airship was successfully winched onto the masting system and then released; the first airship mooring of its kind.

The flight trials demonstrated the viability of the mechanised mooring concept for airship applications. The information gained during this trial was used to address potential improvements to airship ground handling operations, safety and ground maintenance activities. These areas have been incorporated into a conceptual masting system.

Introduction

Since the dawn of the airship age nearly a century ago the problems associated with ground handling this unique aircraft have been considerable. The small early airships were easily handled with few people, however, as the size increased a virtual army was required to ensure safe operations.

During the Second World War the U. S. Navy expanded their Lighter-Than-Air (LTA) fleet from a few non-rigid airships to a peak of more than one hundred and thirty. During those years 90% of all airship accidents occurred during ground handling. However, as there was abundant manpower to act as ground crew, very little effort was expended in developing labour saving or safety enhancing ground handling devices. It was not until after the war with the advent of still larger airships (up to 43,000 m^3) and smaller manpower budgets that new ground handling systems were examined. Perhaps the most successful ground handling system to date appeared in the 1950s when the U. S. Navy developed a ground handling "mule"; this was designed to replace the crew on the handling lines. Although the mules reduced the number of ground personnel to approximately ten, the mules themselves were very heavy, expensive and complex.

Today, the airships that are operated commercially are relatively small (7,000 m^3) and require a modest number of ground crew (up to 15). However, a modern military airship would undoubtedly be considerably larger (over 12,000 m^3). Unless new ground handling systems are developed the large ground crew and limited operating wind speeds may mean that military airships would not be viable.

The Defence Evaluation and Research Agency (DERA) in the United Kingdom has been conducting an extensive research programme investigating airships for military roles. A key element in this work has been ground handling. Contracts were let for two prototype mechanical systems to be developed, one of which was for a mobile mast truck, "the Hydra Mast", which utilised advanced hydraulic systems to replace all but three of the ground crew. The other, the subject of this paper, was based on a modified mooring system developed by TCOM for aerostats.

Aerostat Mooring System (MS) Description

In 1971 TCOM began operations in a new venture using tethered aerostats to perform communications and surveillance missions. A non-mobile mooring system

* Member, AIAA

was developed which would safely launch, retrieve and fly aerostats in moderate to severe weather conditions while using a ground crew of five. Furthermore, the world wide TCOM aerostat operations do not use hangars for inflations, deflations or maintenance. During the last 25 years of operations thousands of aerostat take-offs and landings have been conducted without a single accident. This safety record plus the ability to launch and recover in ground winds in excess of 40 knots suggested that airships may be able to benefit from a ground handling design based upon the principles of the aerostat system. A brief description of the mooring system follows; it is the same baseline system used in the demonstration. It is a very heavy structure specifically designed for aerostat operations, but a refined version meant for airships could be mobile and light weight. Later in this paper a discussion of a future system development is presented.

An overall line drawing of the MS is shown in Figure 1. The MS is a rotating platform which is free to weathervane. In light wind conditions or during the landing approach of the aerostat, the MS can also be rotated by the operator to align it directly with the wind.

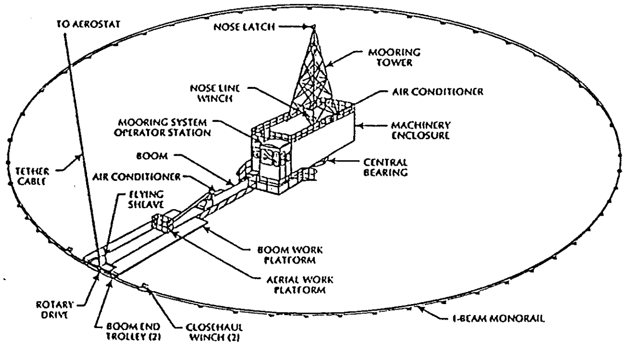

Figure 1. Aerostat Mooring System

The major components of the MS are:

- Machinery Enclosure - Contains the diesel-hydraulic power units, the high-speed capstan winch and the tether storage drum.
- Central Bearing - A 2.44 metre diameter ball bearing upon which the machinery enclosure rotates.
- Mooring Tower - A structural tower supporting the nose latch assembly matching the nose cone height of the aerostat.
- Boom & Boom Work Platform - The boom extends from the machinery enclosure outward to the end which is supported by trolleys on the monorail. The outer end of the boom has a large work platform and rails on top of the boom support a mobile aerial platform for access to aerostat electrical and mechanical equipment.
- Monorail Assembly - A circular rail with a radius of 29.8 metres on which the boom end rides. The monorail captures the boom end so that it cannot lift clear of the rail under high uplift tether loads.
- Operator's Console - The operator sits within the control cab on the end of the machinery enclosure adjacent to the boom. From this vantage point the operator controls all movement of the MS and the various aerostat handling line winches.

Aerostat Ground Handling Procedures

Figure 2 shows the location of the nose line, close haul lines, mooring lines and the tether of a TCOM 71M® aerostat. During take-off, landing and mooring the various handling lines are employed as described below and illustrated in Figures 3 through 8.

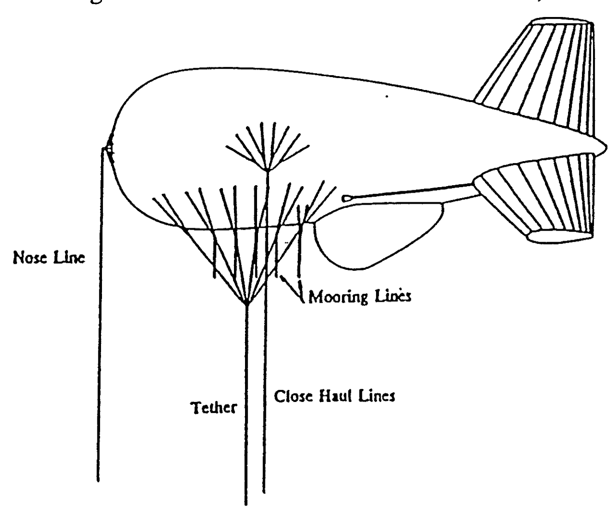

Figure 2. TCOM 71M® Aerostat

In Figure 3 the aerostat is moored to the MS with five mooring lines on each side of the aerostat attached to hard points along the edge of the boom work platform. The close haul lines are wrapped on their respective winches with minimum slack in the lines. In order to launch the aerostat the close haul lines take tension 'to pull the aerostat downward, relieving the strain on the mooring lines which are then detached by the ground crew. The aerostat is allowed to rise to a 7° to 10° nose down attitude by paying out the close haul

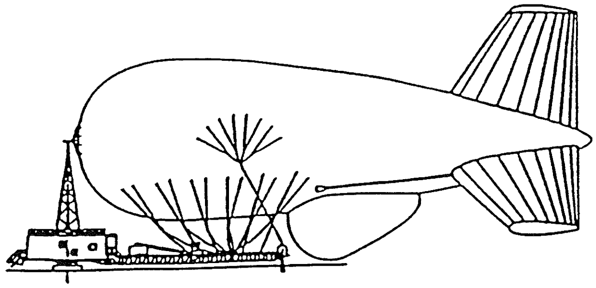

Figure 3. Aerostat in Moored Condition

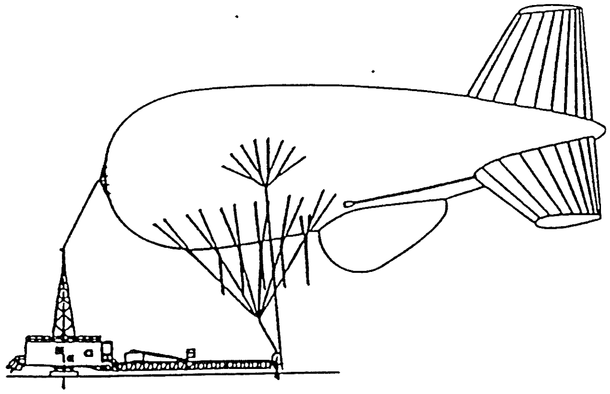

Figure 4. Aerostat Takes Tension on Tether

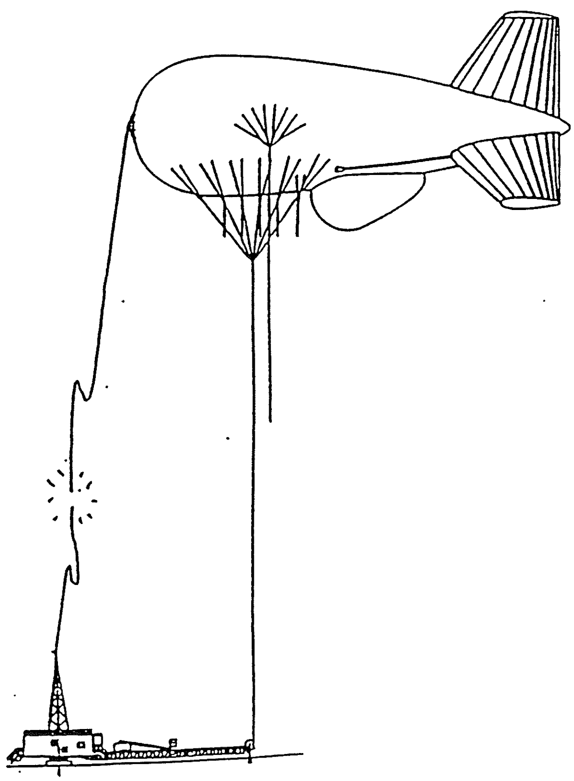

Figure 5. Aerostat Breaks Tag Line

lines. In this position the tension on the close haul lines is pulling the aerostat nose away from the mooring tower. At this point the nose latch is unlocked, the nose line and the close haul lines are paid out until the tether comes under tension as in Figure 4. As the payout continues the aerostat is controlled by tension in the nose line. As the nose line leaves the winch, it is connected to a tag line with a weak link. When the end of the tag line is reached, the tension in the nose line breaks the weak link (Figure 5.). From this point the aerostat is winched rapidly to its operating altitude.

The recovery of the aerostat is the reverse of the launch. The aerostat is brought down on the tether to

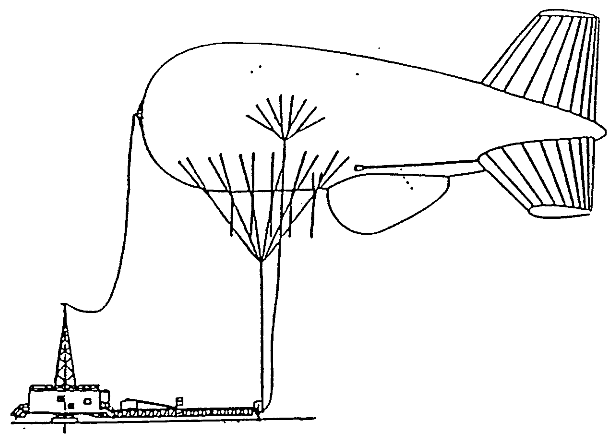

Figure 6. Aerostat Lines Attached

a position as shown in Figure 6. The nose line has been connected to the tag line and pulled through the mast head to its winch at the base of the tower. The close haul lines have been attached to their respective winches.

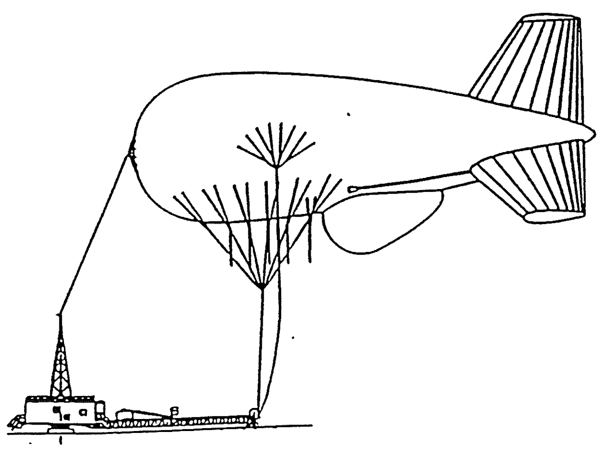

Figure 7. Controlled by Nose Line and Tether

In Figure 7, tension is then taken on the nose line in order to control the nose position in both pitch and yaw as the aerostat is slowly winched downward by the tether and the nose line.

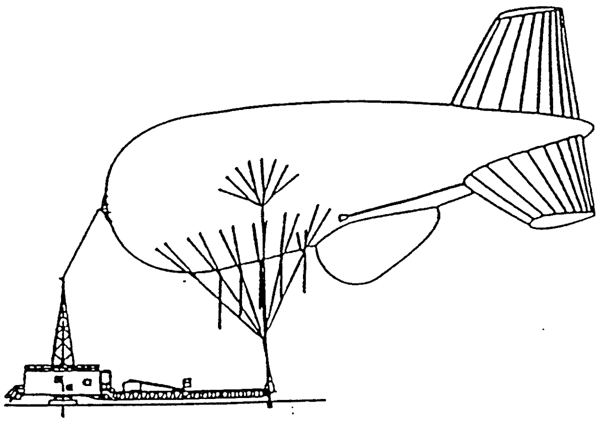

Figure 8. Tension Taken on the Close Haul Lines

In Figure 8 the tether winch has been stopped and tension has been taken on the two close haul lines. The inhaul on the nose line and close haul lines is continued until the nose is latched to the tower top. The aerostat is winched down further by the close haul lines until the mooring lines can be attached to the hard points on the work platform. The close haul lines are slackened and the aerostat is now back in the position as shown in Figure 3.

The only purpose of the close haul lines is to take the place of the tether during the last few metres of the aerostat recovery (or the first few metres of the aerostat launch) since the tether confluence point cannot be spooled over the flying sheave. In the moored condition, the loads on the aerostat are taken on the mooring lines and the nose cone while the close haul lines have a minimum tension as a safety feature. It is the division of aerostat loads between the nose and mooring lines which protect and support the aerostat in high and shifting wind conditions.

Demonstration Objectives

The major objectives of the demonstration were to:

1) Design and demonstrate a mechanised masting system for the safe launch and recovery of a Skyship 600 airship;

2) Evaluate the potential improvement to airship ground handling and safety which may result from mechanised masting;

3) Evaluate the potential improvement and added flexibility to ground maintenance which may result from the demonstrated mooring concept;

4) Evaluate the potential for the mooring concept to reduce manpower required for ground handling operations. Extrapolate observations to consider future, larger airships; and

5) Evaluate results from the demonstration and applicability towards a conceptual masting system.

Airship Modifications

The method selected for testing the mechanical ground handling system concept required modifications to both the airship and the aerostat mooring system.

In order to make the airship "look" like a tethered aerostat it was necessary to attach a tether which will be called the "down haul line". It was calculated that this line should be attached slightly aft of the center of gravity so that tension on that line would tend to pull the airship to a tail down attitude.

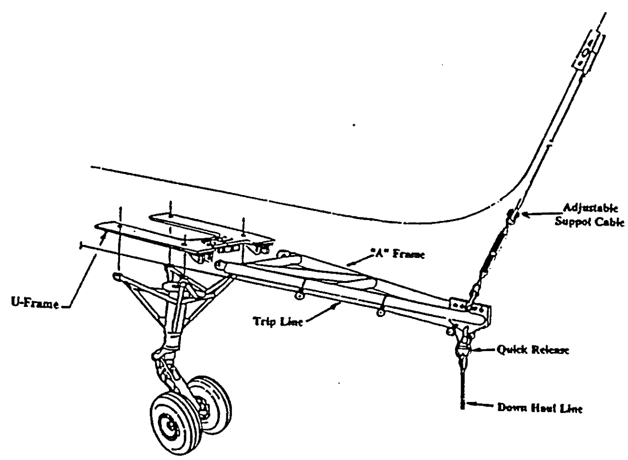

Figure 9. Down Haul Line Installation

An "A" frame 1.91 metres in length was manufactured of structural aluminium and mounted beneath the landing gear of the airship. An adjustable cable was fitted between the "A" frame and the internal suspension cable at the rear of the gondola, shown in Figure 9. A down haul line 45 metres in length was attached to a quick release fitting at the aft end of the "A" frame. The quick release was controlled by the pilot using a trip line.

The other modification to the airship consisted of a 45 metre nose rope extension which was connected to the airship wire nose pendant by a removable metal link. This enabled the airship to approach the landing site at a height of about 150 feet and place the nose line and the down haul line within the reach of the ground personnel.

Mooring System Modifications

Mooring Tower - A new mooring tower to match the height of the airship nose was constructed of steel and mounted on top of the machinery enclosure. An airship mast head was mounted on top of the new tower. Since this assembly was designed to feed the nose line down the outside of the tower, a turning block was mounted on the top of the machinery enclosure aft of the tower base. The nose line could be fed down the outside of the tower and then be turned to reeve onto the normal nose line winch at the middle of the tower base.

Boom Extension - The normal aerostat flying sheave assembly was removed from the boom end and a steel extension 8.4 metres in length was added. The aerial tower was removed from the boom and its carriage was modified to mount the airship down haul line turning block. Two winches, one on the boom structure and one below the boom extension were located so that they could be used to move the modified carriage along the boom. Also, one of the aerostat close haul winches was mounted beneath the boom extension so that the airship down haul line could be reeved onto it. Appropriate sheaves and turning blocks were mounted on the boom extension so that all lines would be directed to their respective winches. Figure 10 is a side view of the boom extension, carriage, turning blocks and winch arrangement.

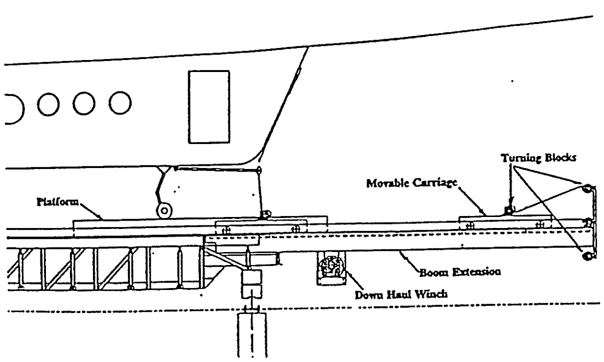

Figure 10. Boom Extension Modification

A landing platform 2.44 metres wide by 6.1 metres long was constructed above the boom. With the turning block carriage at the end of the boom, the airship could be winched down so that the nose would be clear of the mooring tower. Once the nose probe of the airship was locked into the mast head, the down haul carriage could be moved forward so that the down haul line pulled straight down until the airship landing wheel was held firmly in contact with the platform.

Trials Plan

A trials plan was agreed between TCOM, Airship Management Services (AMS) (the airship operator), and DERA. Flight tests were conducted during the week of 21 to 25 October 1996. This was a team effort with all parties playing key roles.

Airship Masting Demonstration

Monday, 21 October 1996

A review of the mooring system was conducted to evaluate positioning for the DERA video equipment. DERA/UK MOD personnel coordinated the audio-to-video connections for the mooring system and airship gondola with TCOM technicians and airship ground crew members. Modifications to the airship and a Trial Plan briefing was scheduled for Tuesday morning.

Tuesday, 22 October 1996

The Test Plan briefing was conducted. During the meeting, the TCOM test director presented the Trials Plan to ensure all attending participants understood the overall objectives and their respective roles. The pilot was apprehensive about the location of the mooring system with respect to surrounding trees, power lines and houses. With southwesterly winds the airship would have to approach the mooring system over the trees and houses. The first flight was scheduled for Wednesday at sunrise.

Wednesday, 23 October 1996

On Wednesday morning, winds were steady and southwesterly at approximately 5 knots. Based on the wind direction, the pilot was unwilling to attempt mooring the airship but agreed to make "dry run" approaches. The ground crew consisted of:

- The test director (TD), positioned inside the monorail to the starboard side of the machinery enclosure;
- The airship ground crew chief, positioned on top of the machinery enclosure for a head-on view of the approach;
- Two operators in the mooring system control cab, one aligning the MS with the airship, the other operating the nose line and down haul line winches;
- A nose line runner at the end of the boom collecting the nose line;
- A down haul line attendant outside the monorail to grasp this line and connect it to its in-haul winch;
- An attendant positioned on top and at the end of the boom for connecting the nose line to the tag line for feeding up through the mooring tower;
- An attendant on top of the machinery enclosure for pulling the tag line through the nose latch and connecting it to its in-haul winch;
- An additional attendant on top of the enclosure to observe the nose latch and climb the mooring tower if any manual adjustments are necessary; and
- An additional attendant outside the monorail for observation and assistance where necessary.

Four landing approaches to the MS were executed by the pilot. On each approach the nose and down haul lines were collected by the appropriate crew members as the airship achieved and sustained a proper approach position. These passes demonstrated that the airship could be manoeuvered into position and hover there long enough for the ground personnel to retrieve and hold the lines while awaiting further instruction. During these passes the wind direction at ground level was southwesterly at 8 knots while the wind velocity at 200 to 300 feet was reported by the pilot to be approximately 25 to 30 knots.

<u>Thursday, 24 October 1996</u>

On Thursday morning, the airship took off for additional flight tests. Weather conditions at the time were 16.4°C with steady 6 knots westerly winds. It was agreed that connection of the mooring lines and an in-haul attempt could occur.

Two approaches were made and on both occasions the nose line was quickly connected, however, the downhaul line took much too long to attach. This delay caused the airship attitude and position to drift; the pilot, therefore, initiated "Go around" procedures. The first was accomplished very quickly, however, on the second attempt the order to abort was not heard by the winch operator. The airship Crew Chief, sensing the difficulty, immediately cut the nose line to release the airship.

These first attempts at mechanised mooring revealed two clear areas that needed improvement: the process for connecting the down haul line and communication between the pilot, test director, ground crew chief and winch operator. As the sun was rising, causing an increasing chance of thermal ground turbulence, it was decided to reschedule further flight testing for late afternoon. A briefing and operational review was called to discuss the attempts and the areas needing improvement.

In summary, the conclusions from the meeting were:

- Only the test director and winch operator should talk over the mooring system communications link.
- The airship should be kept in a slightly nose down attitude at all times. The test director must call estimates of nose position to the winch operator and pilot.
- The test director must inform the pilot when the down haul line connection is made.
- A shorter tag line for the down haul line should be used and the weak link eliminated.

At about 5:00 p.m. local time the airship again took off to continue the masting trials. Winds were southwesterly at a steady 5 knots on the ground. The ground temperature was approximately 22° C. On this, the seventh approach, a successful docking with the mooring system was made.

The successful masting is described below:

1. The airship was launched in the normal fashion. The extended nose line as well as the down haul line were tended by members of the AMS crew to insure that they did not foul or tangle.

2. The airship was flown in a normal approach for landing except that it came to a hover about 150 feet directly over the mooring system as shown in Figure 11.

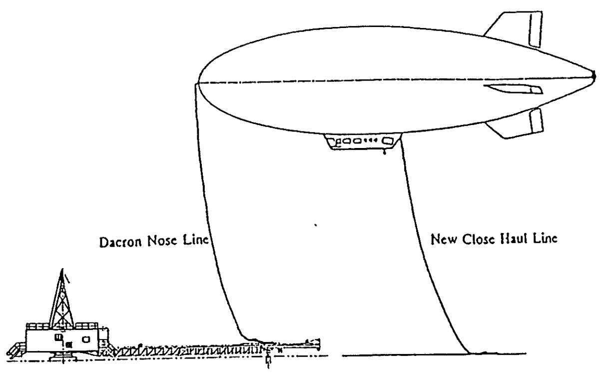

Figure 11. Airship in Approach Position

3. The nose line was attached to the tag line. The nose line handler then attached it to the nose line winch. As soon as the line was attached, the operator took up the slack.

4. The down haul line was retrieved but was not attached to the winch until tension was taken on the nose line. Tension was then taken evenly on both handling lines.

5. At this point the airship pilot ballasted the airship to a light condition by releasing 80 kg of water ballast.

6. The pilot adjusted the airship thrust to keep it from over riding the mast.

7. The technical director (TD) consulted the pilot by radio to ascertain that they were both ready to continue with the landing sequence.

8. The winch operator began paying in on both handling line winches while the TD observed the airship attitude and signalled for increased or decreased nose line inhaul speed to maintain a comfortable nose down attitude as shown in Figure 12.

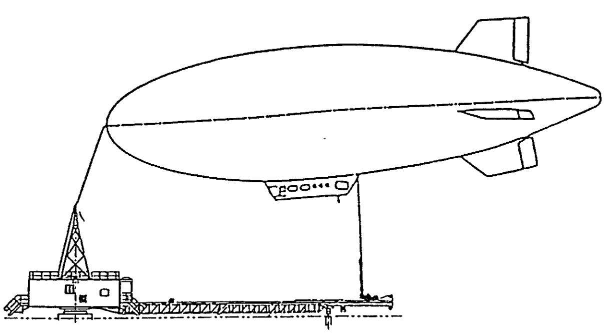

Figure 12. Airship Being Hauled Down

The winch operator inhaulled on both winches In a manner very similar to an aerostat recovery. The inhaul rate was reduced as the airship approached the tower. The airship was about 10 degrees nose down as the nose probe approached the nose latch.

9. The winch operator used a very slow inhaul rate as the nose probe engaged in the nose latch.

10. With the nose latch locked, the down haul winch was stopped and the operator moved the down haul turning block carriage to the forward most position as shown in Figure 13. (It was then noted that the airship nose pendant had broken).

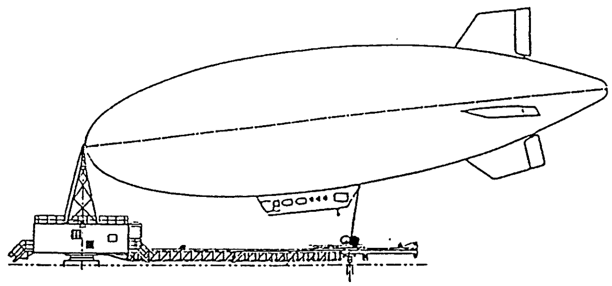

Figure 13. Turning Block Carriage Moved

11. The operator continued to haul the airship down until the landing wheel was firmly in contact with the platform on top of the mooring boom (Figure 14.)

12. The airship remained on the mast with its engines running for five minutes whilst the damage to the nose pendant was assessed and the take off procedure was discussed.

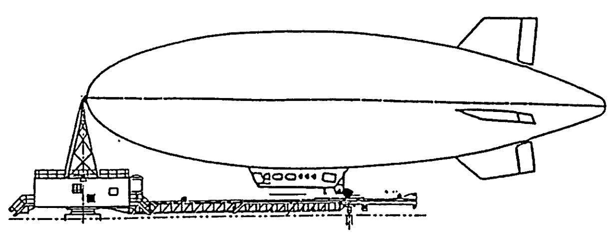

Figure 14. Airship Securely Moored

13. The takeoff procedure should have been a reverse of the landing procedure. However, due to the nose pendant failure the procedure was modified.

14. The down haul line was winched out until the

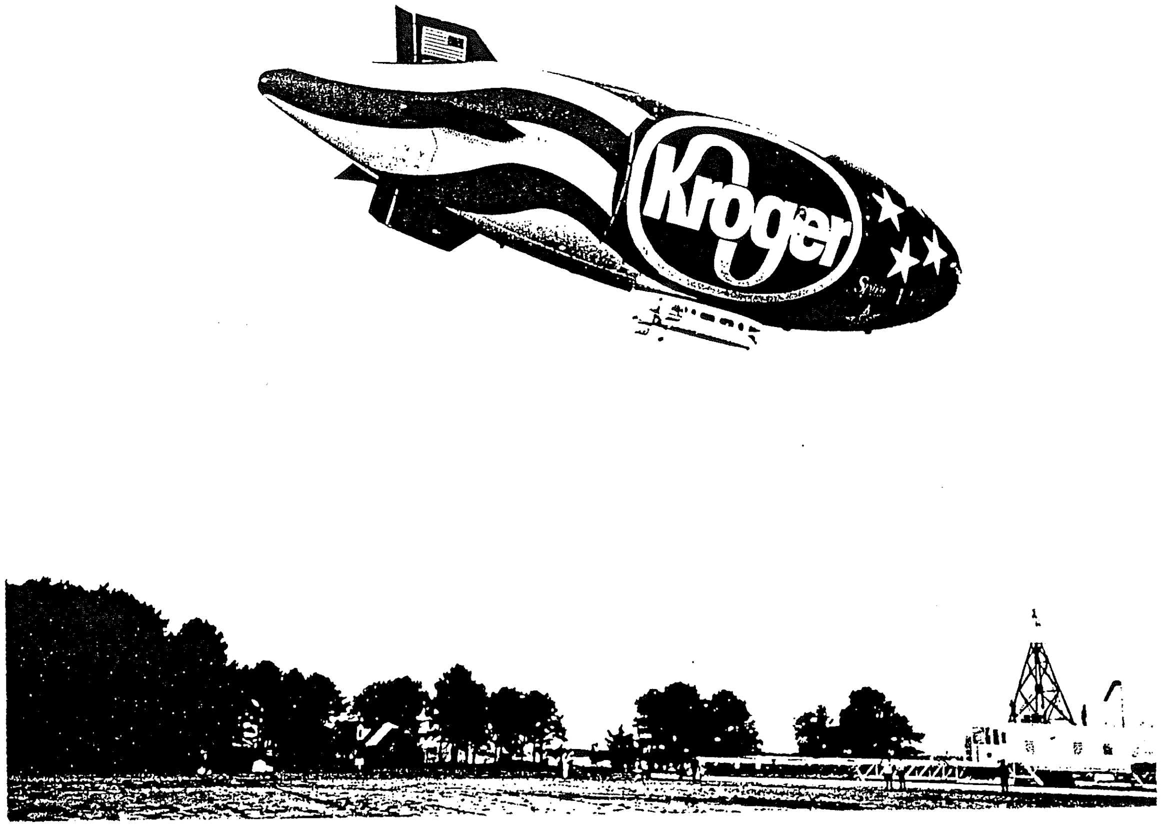

Figure 15. Airship Approaching Mooring System with Lines Attached

Figure 16. Landing Completed. Airship Firmly Held on Mooring System

airship was about 10° nose down while still locked to the tower. The turning block support trolley was moved aft so that the down haul line tended to pull the airship away from the tower nose latch. At this point the nose latch was released; the airship backed away smartly as the nose came to about +10°. The pilot tripped the down haul line and the airship flew safely away from the mooring system.

Figure 15 shows the Skyship 600 with the nose line and downhaul line attached to the mooring system as it is slowly winched down for a masting. Figure 16 shows the airship stationary on the masting system after the successful landing.

Friday, 25 October 1996

Due to the damage caused to the nose line and mast head, and the lack of additional spares, no further masting attempts could be undertaken. However, it was agreed that additional test flights would occur to demonstrate the connection and tensioning of the airship mooring lines. The airship would be winched to an height of approximately 15 feet above the tower, but the airship would not be masted. Two successful approaches were made. On both occasions the airship was winched to within 15 feet of the mast. It was held in that position for several minutes demonstrating the confidence in the system. The lines were then paid out and the airship released.

A third approach was attempted without the airship landing for re-ballasting. Now more than 120 kg light, the handling lines were collected as on the prior approaches. Just as tension was being taken on the handling lines one of the high pressure hydraulic lines in the rotary drive circuit of the mooring system burst. The TD director immediately announced an abort. Both lines were paid off of the winches and the airship flew away for a final landing.

After the completion of flight operations, the airship pilot, ground crew chief and the test director provided recorded interviews to the DERA personnel.

Discussion of Test Results

The flight tests conducted during the week of 21 October 1996 demonstrated the mechanised masting of an airship for the first time. In general, the concept originally proposed by TCOM worked as planned. As described, the conduct of the trials occurred in steps, with progress and adjustments made throughout each day. On Wednesday, it was discovered the airship could successfully approach the TCOM mooring system given the physical constraints of its location and less than optimal wind direction.

During the flights on Thursday morning, it became apparent that various adjustments were necessary. These attempts also revealed the ease with which the emergency escape procedures could be accomplished. The quick release of the down haul line worked, and the nose line was easily manually cut when the winch pay out rate was not sufficient. These adjustments and the experience gained during the morning activities led directly to the successful masting on Thursday evening. In one and a half days, the pilot and newly assembled ground crew gained sufficient knowledge and experience to successfully moor the airship on Thursday evening.

Even during the successful masting, additional observations were made regarding other necessary improvements to the masting system. The nose latch plate requires adjustment to accommodate masting from a nose down approach to prevent damage as it rotates to a more horizontal direction. The nose wire, if frayed or worn from use, is susceptible to tensile break. This can be addressed through eventual design changes to the latching mechanism and the type of winch employed during in-haul or a change to a dacron or other suitable material line. The winch can be designed to operate with less tension and more sensitive controls. The addition of a "nose latched" indicator would alert the winch operator to stop in-hauling.

The flights on Friday indicated that the process did improve with repetition and experience of the personnel. The process of gathering, connecting, and tensioning the handling lines was performed much more efficiently when compared to one day earlier. Although the airship was not latched, the mooring system demonstrated the ease of connection and in-haul control as the airship was lowered and held to a position just above the mooring tower.

Concept

Any future design must consider the airship and mooring system as a complete system. The nose cone section of the airship must be designed to withstand the shock of engaging the mooring tower latch mechanism

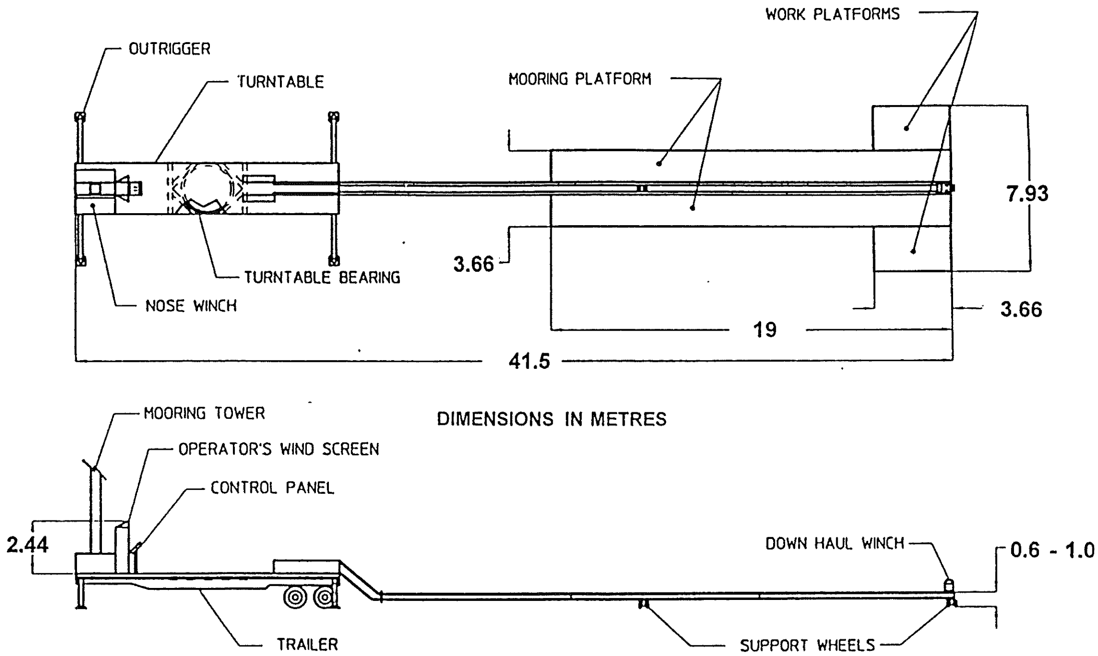

Figure 17. Proposed Airship Mooring System Concept

under dynamic mooring conditions. In addition, the airship should be equipped with a retractable nose line.

The airship should be equipped with a retractable down haul line attached aft of the center of gravity. It should be attached to the airship with a quick release mechanism which can be actuated by the airship pilot or the mooring system operator.

The thrust vectoring system must allow for the propellers to be rotated upward from the normal position by at least 120° and be designed to develop significant thrust when vectored up and aft. The airship should be designed to operate as a truly lighter-than-air vehicle. At takeoff the airship should be at equilibrium or slightly light. For landing, the airship should also be in an equilibrium or slightly light condition. This will mean that the airship should be equipped with some form of water ballast recovery system.

By using a combination of water ballast release and upward thrust the airship could be made to appear statically light by as much as 15% of the gross lift. A lightness in this order of magnitude would add stability to the airship and make it behave very much like a tethered aerostat.

The proposed mooring system concept, shown in Figure 17, consists of a turntable-platform mounted on top of a standard 12.2 metre road trailer, a retractable and telescoping mooring tower and a boom of adjustable length. The trailer is equipped with outriggers which are lowered to add stability and increase the overturning resistance of the system. The boom, attached at one end of the rotating table, is supported at mid span and at the outer end. The boom is adjustable in length by the addition or removal of boom sections. An electro-hydraulic winch is mounted at the end of the boom for the inhaul and outhaul of the down haul line. There is a mooring platform sufficiently wide to allow easy access to the main door of the airship. At the boom end, in the area beneath the airship engines, work platforms can be attached to the boom to permit access to the engines for repair or replacement even as the airship weathervanes on the mooring system. These platforms can either be mechanised or other platforms added to provide access to other areas of the airship.

Conclusion

The flight trials demonstrated the viability of using an aerostat mooring system for airship applications. The information gained during this trial has been used to address potential improvements to airship ground handling operations, safety and ground maintenance and have been incorporated into a conceptual masting system.