013320

NASA Contractor Report 202308

SEADYN Analysis of a Tow Line for a High Altitude Towed Glider

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December 1996

Prepared for
Lewis Research Center
Under Contract NAS3–27186

National Aeronautics and
Space Administration

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Introduction

The concept of using a system, consisting of a tow aircraft, glider and tow line, which would enable subsonic flight at altitudes above 24 km (78 kft) has previously been investagated[1,2,3]. The preliminary results from these studies seem encouraging. Under certain conditions these studies indicate the concept is feasible. However, the previous studies did not accurately take into account the forces acting on the tow line. Therefore in order to investigate the concept further a more detailed analysis was needed. The code that was selected was the SEADYN cable dynamics computer program which was developed at the Naval Facilities Engineering Service Center[4,5]. The program is a finite element based structural analysis code that was developed over a period of 10 years. The results have been validated by the Navy in both laboratory and at actual sea conditions[6,7].This code was used to simulate arbitrarily-configured cable structures subjected to excitations encountered in real-world operations. The Navy's interest was mainly for modeling underwater tow lines, however the code is also usable for tow lines in air when the change in fluid properties is taken into account. For underwater applications the fluid properties are basically constant over the length of the tow line. For the tow aircraft / glider application the change in fluid properties is considerable along the length of the tow line. Therefore the code had to be modified in order to take into account the variation in atmospheric properties that would be encountered in this application. This modification consisted of adding a variable density to the fluid based on the altitude of the node being calculated. This change in the way the code handled the fluid density had no effect on the method of calculation or any other factor related to the codes validation.

This study is based on the analysis performed in reference 1. From this previous analysis it was determined that under certain conditions the concept of using a towed glider as a high altitude research platform was feasible. Based on these results a more detailed analysis of the tow line using the SEADYN code was warranted.

Analysis

The concept of using a towed glider for subsonic high altitude atmospheric research may offer some advantages over other more conventional methods. The main advantage is the elimination of the need to operate a powerplant, such as an internal combustion engine, at very high altitudes. With a tow aircraft / glider system the thrust is generated at a lower altitude, where the atmospheric density is much greater, while the glider and scientific instruments are located at a much higher altitude. This configuration is shown in figure 1. However, as with most things there are tradeoffs. The elimination of the need to run a powerplant at high altitudes requires the use of a very long tether or tow line in order to pull the glider through the atmosphere at the altitude of interest. The SEADYN code was used to try and determine the tow line characteristics necessary to accomplish this task. The results that were generated show the required tow line diameter and length that were required for a given set of conditions as well as the maximum tension within the tow line. This maximum tension is in effect the additional drag the tow aircraft must overcome in order to pull the glider along at the desired speed. In other words the tow aircraft must be capable of sustained flight at its designated altitude with enough excess thrust available to match or exceed the drag of the tow line and glider. One of the objectives of this analysis was to try and determine if this excess thrust requirement for the tow aircraft was realistic for the cruise altitude at which a tow aircraft would fly.

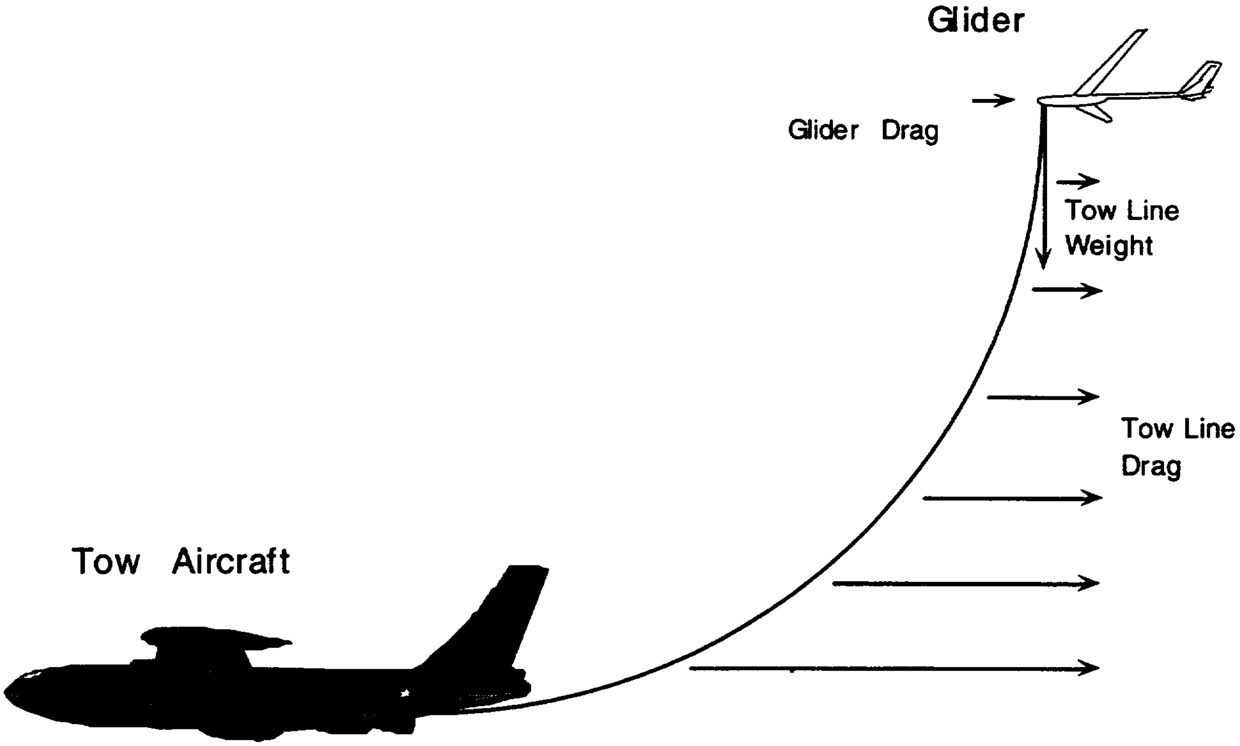

Figure 1 Tow Aircraft / Glider Configuration

The variables used to specify the problem are listed below.

1. Glider / Tow Aircraft Vertical Separation Distance
2. Tow Line Strength
3. Velocity

In the analysis these variables were altered in order to try and determine what impact they had on the tow line drag. The tow line drag results were also used to make an assessment of the point at which a given variable or combination of variables makes the concept unfeasible. Aside from these variables other characteristics of the system had to be specified. These specifications were not changed throughout the analysis.

1. Glider Aircraft Lift / Drag	24
2. Tow Line Material:	Carbon VHS Composite Density 1530 kg / m^3 (95 lb / ft^3) Ultimate Strength 1.9 GPa (275 ksi)

There are also a number of variables that are used to set up the SEADYN analysis such as fluid properties and node, element and flow field specifications. These variables are specific to the analysis method used by SEADYN and remained the same for all cases examined. A example of the SEADYN input file used in the analysis is given in the Appendix. Also a complete description of all the input variables used by the SEADYN code is contained in reference 4.

Results

The initial set of results generated with the SEADYN code were for a tow aircraft altitude of 20 km and a glider velocity of M 0.4. These are summarized in table 1 and figure 1.

Glider Altitude km (ft)	23 (75,460)	24 (78,740)	25 (82,020)	26 (85,300)	27 (88,580)	28 (91,860)	29 (95,140)	30 (98,430)
Tow Line Weight kg (lb)	20 (44)	36 (78)	53 (116)	77 (170)	104 (228)	128 (282)	152 (334)	183 (402)
Tow Line Drag N (lb)	1757 (395)	2432 (547)	3157 (710)	3907 (878)	4573 (1028)	5199 (1169)	5830 (1311)	6413 (1442)
Tow Line Length m (ft)	6948 (22,795)	9118 (29,915)	10,406 (34,140)	12,135 (39,813)	13,889 (45,568)	15,187 (49,826)	16,104 (52,835)	17,430 (57,185)
Tow Line Diameter cm (in)	0.155 (0.061)	0.180 (0.071)	0.205 (0.081)	0.230 (0.091)	0.249 (0.098)	0.265 (0.104)	0.280 (0.110)	0.295 (0.116)

Table 1 Tow Line Specifications for Increasing Glider Altitude

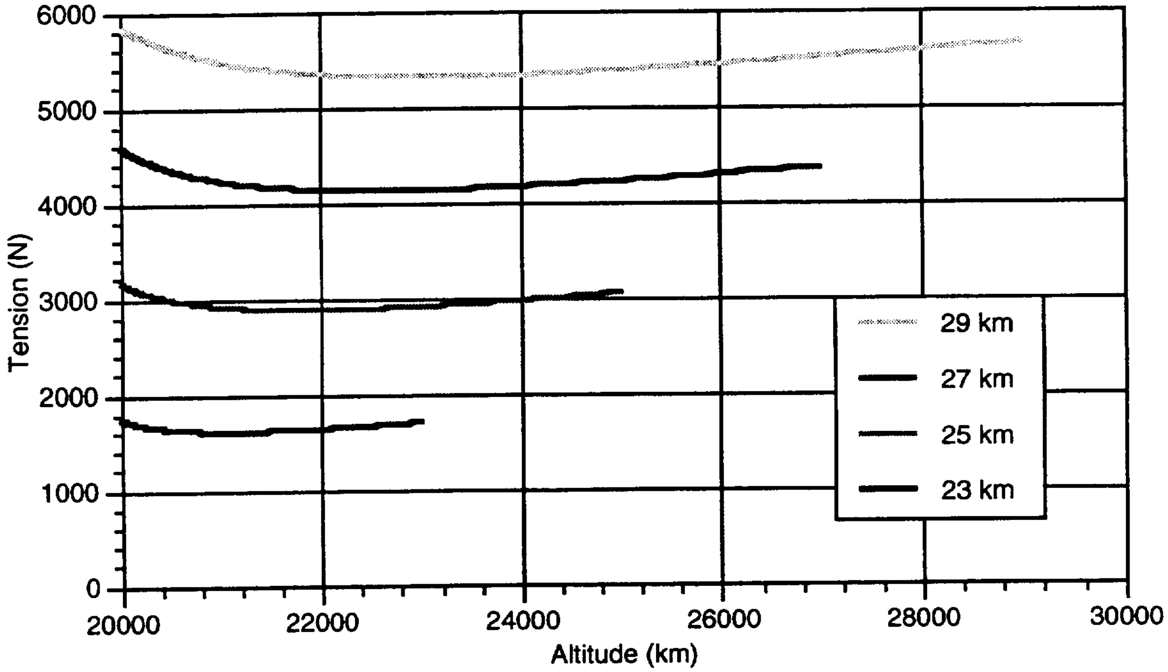

Figure 1 Tow line Tension as a Function of Altitude for Various Glider Altitudes with Tow Aircraft at 20 km

The code was also used to examine the effect a change in the value of certain variables had on the tow line results. Results were generated for different values of tow aircraft altitude, tow line material factor of safety and glider Mach number. These results were generated by altering one of the variables from the base case analysis. The base case specifications are given in column one of table 2 and in figure 2. Each of the variables that was altered represents a condition that is dependent on the capabilities of a particular component of the system. These results are shown in table 2 and figures 3 through 5.

Tow Aircraft Altitude km (ft)	20.0 (65,617)	21.5 (70,535)	18.5 (60696)	20.0 (65,617)	20.0 (65,617)	20.0 (65,617)	20.0 (65,617)
Material Factor of Safety	2.0	2.0	2.0	1.5	1.0	2.0	2.0
Glider Mach #	0.4	0.4	0.4	0.4	0.4	0.35	0.30
Tow Line Weight kg (lb)	53 (116)	36 (78)	53 (116)	77 (170)	104 (228)	128 (282)	152 (334)
Tow Line Drag N (lb)	3157 (710)	1541 (346)	6076 (1366)	2543 (572)	2062 (464)	2175 (489)	1607 (361)
Tow Line Length m (ft)	10,406 (34,140)	8027 (26,335)	13,698 (44,941)	10,404 (34,134)	10,411 (34,157)	10,406 (34,140)	10,420 (34,183)
Tow Line Diameter cm (in)	0.205 (0.081)	0.145 (0.057)	0.285 (0.112)	0.160 (0.063)	0.118 (0.046)	0.171 (0.067)	0.147 (0..058)

Table 2 Tow Line Specifications for Variations on Input Parameters

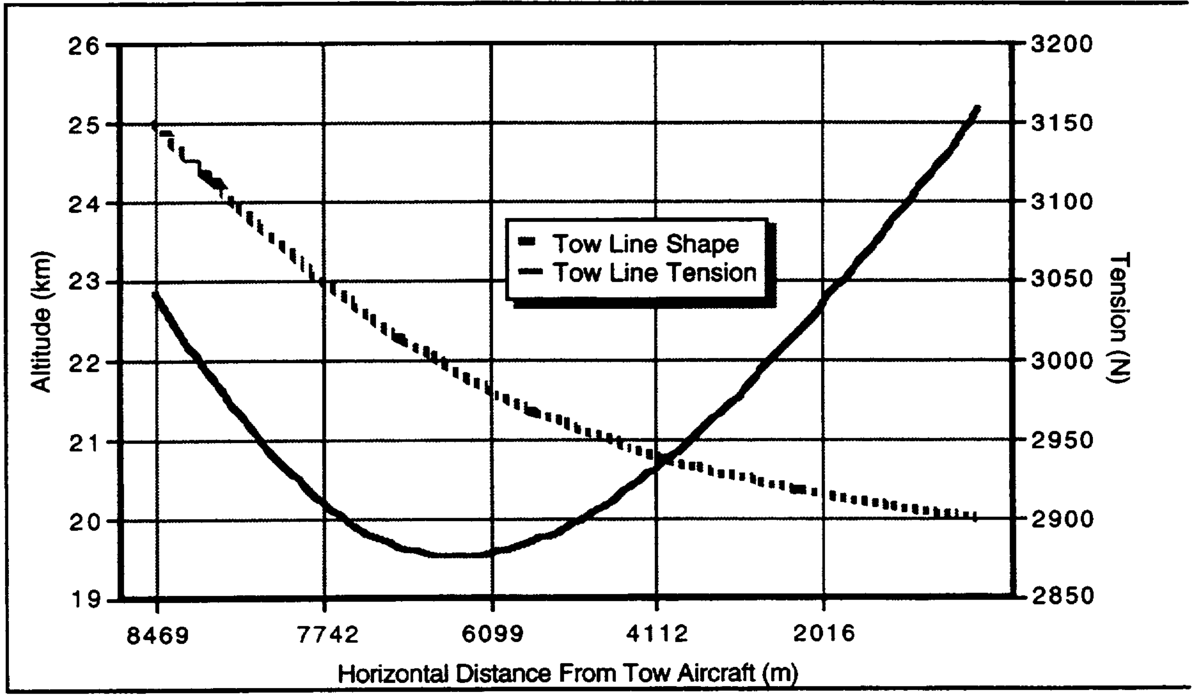

Figure 2 Tow Line Shape and Tension for Base Case Values

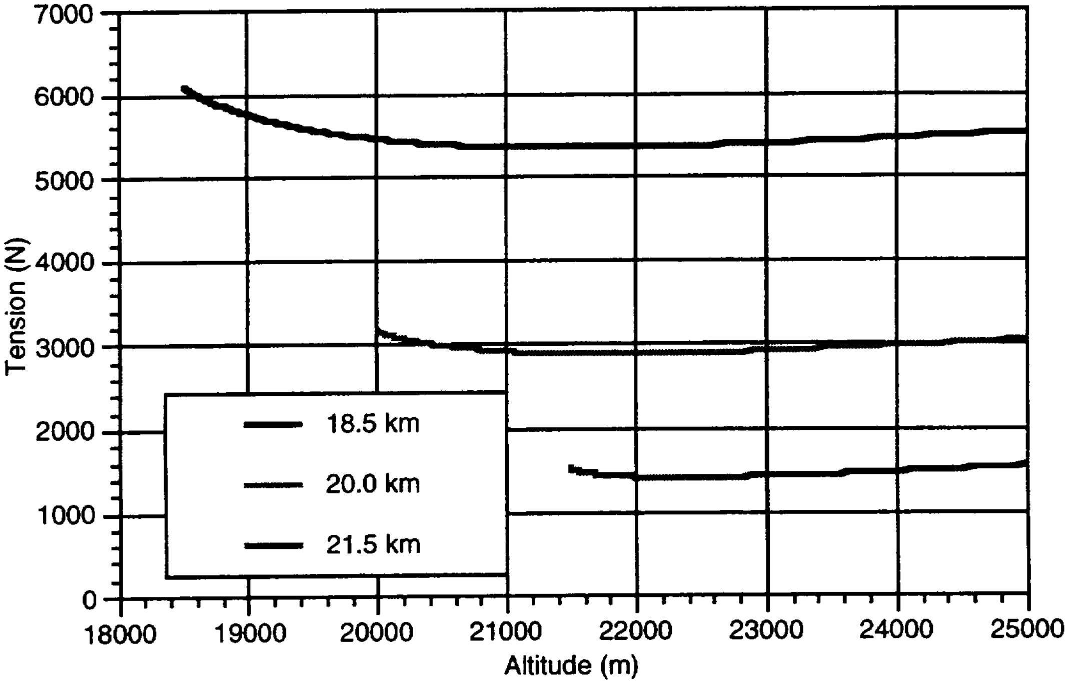

Figure 3 Tow Line Tension Versus Altitude for Various Tow Aircraft Altitudes

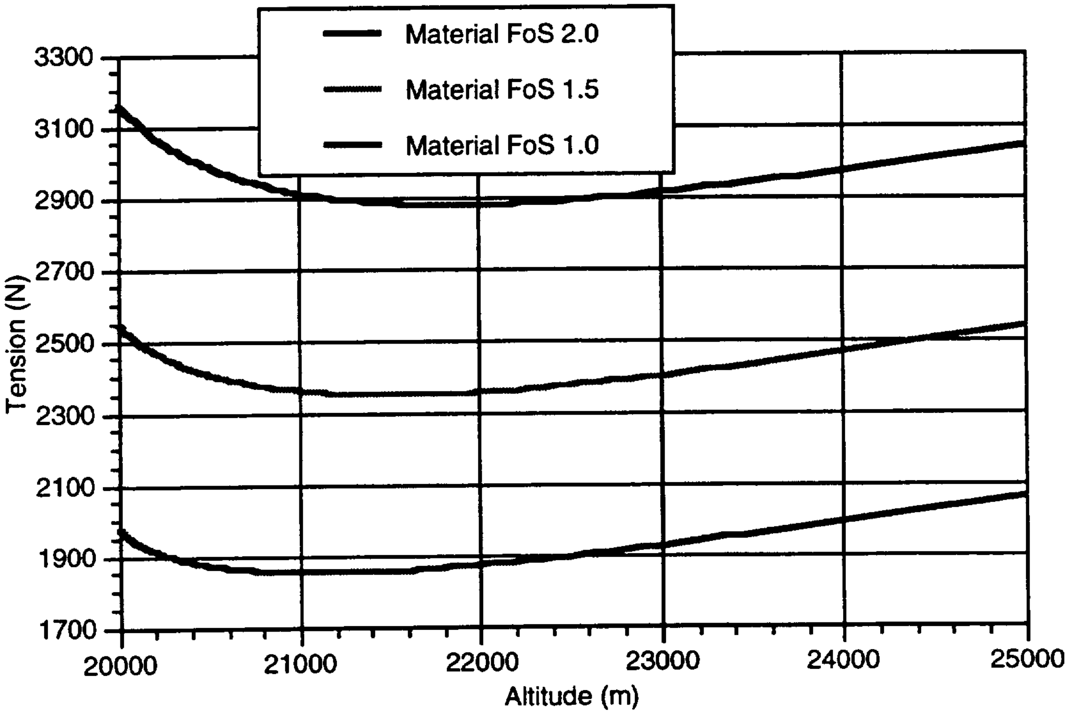

Figure 4 Tow Line Tension Versus Altitude for Various Material Factor of Safety

Values

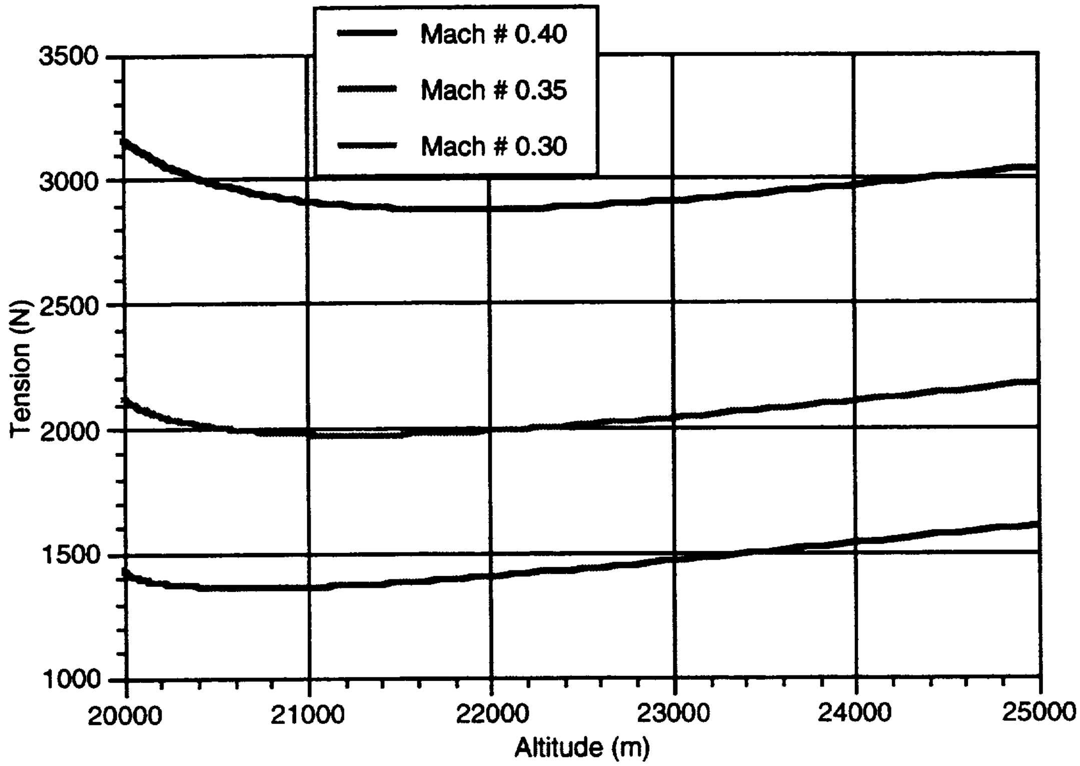

Figure 5 Tow Line Tension Versus Altitude for Various Glider Mach Number Values

The tow aircraft altitude would depend on the ability of the tow aircraft to generate the necessary amount of thrust at the desired altitude to overcome the tow line and glider drag. As the tow aircraft altitude increases the system drag is decreased considerably as can be seen in figure 3. Over the range of tow aircraft altitudes examined, the tow line drag decreased by a little less then 75% between the lowest (18.5 km) and highest (21.5 km) altitude. This substantial drop in drag however, depends on the ability to construct an operational aircraft that can generate excess thrust at these higher altitudes. This may prove as difficult as trying to perform the mission with a powered aircraft instead of a glider. There is definitely a trade off between tow aircraft altitude and tow line drag in the design of the tow aircraft. It is only through this design process that the appropriate altitude for the tow aircraft can be determined.

The reduction in material factor of safety can be thought of as either a more aggressive use of the material stated or as an increase in material strength over the baseline carbon VHS tow line material. The effect of the increase in strength can be seen in figure 4. By decreasing the factor of safety from 2.0 to 1.0 (this can also be thought of as a doubling of the material strength and leaving the factor of safty at 2.0) the tow line drag decreases by approximately 35%.

The velocity the glider flies at has a significant effect on the tow line drag. This can be seen in figure 5. There is a 56% decrease in the tow line drag by decreasing the glider Mach number from 0.4 to 0.3. Aside from the reduction in tow line drag there are other factors that have an influence on the glider velocity. These include the mission requirements and the tow aircraft capabilities. For environmental sampling, flying below Mach 0.4 is desirable. This is to minimize the aerodynamic heating of the gas samples that can occur during atmospheric sampling. With regard to the tow aircraft it may become increasingly difficult to generate excess thrust the slower the aircraft flies. This effect however is greatly influenced by the type of propulsion system the tow aircraft uses. As with the tow aircraft altitude, the trade off between the reduction in tow line drag and the decrease in tow aircraft velocity has to be taken into account during the design process of the tow aircraft.

Conclusion

The results of the SEADYN analysis are similar to those obtained in reference 1. The effect each variable had on the tow line drag was similar. However , the actual values of the drag were different between this analysis and that of reference 1. The SEADYN results produced mostly lower overall tow line drag values. The lower values of tow line drag indicate that it may be possible to apply this scheme to a system with a greater separation distance between the tow aircraft and glider then was suggested by reference 1. These results suggest that by reducing the speed of the glider or the separation distance between the glider and tow aircraft, the drag can be significantly reduced. It must be remembered that in order to achieve a drag reduction by these means requires a much more capable tow aircraft. When evaluating this concept the whole system must be considered.

Any increase in tow line strength will reduce the tow line drag without effecting any other component of the system. An added benefit is that it also reduces the tow line weight. This weight reduction can be though of as an increase in the available payload mass for the glider. The ability to manufacture an extremely long tow line with the required strength is a materials and manufacturing issue that must be considered. Based on this analysis a rough estimate of the requirements for the tow aircraft and tow line can be suggested. The tow aircraft should have the ability to fly at an altitude of around 20 km (~65Kft) and produce at least 2500 N (~550 lb) of excess thrust. Whereas a very thin tow line on the order of 0.2 cm (~.08 in) must be able to be manufactured with a length on the order of 10 km (~34 kft) and with a uniform ultimate strength of at least 1.9 GPa (~275 ksi).

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Appendix: Sample Input File For SEADYN

```
Air towed glider with variable density
Tow plane elevation - 20 km
Total glider weight - 4129 NT
Effective glider drag diameter - 2.3 m
Glider lift/drag   - 26
Line length        - 7300 m
Line diameter      - 0.0025 m
Line unit weight   - 0.07365 NT/m
Line stiffness, EA - 6.77E5 NT
Uses default drag coefficients
Starts from horizontal;
PROB; 101,100,-3,1,W7,5
FLUI; 0,4
BODY; 1,,4129,2.3,-26
BLOC; 1,1            * Glider at node 1
MATE;1,0,.00205,.07365,W9,6.775E5,1,.1
NODE
  1,,9500,,25000,w8,1
  101,W5,20000,1,1,1
NGEN
  99,1,101
ELEM
  1,1,2,,1
  100,100,101,,1
FLOW;1,1,119
TABLE
  1,1,2,1,1,1,1,W11,1,3,9,14,54,27,31,44,59,75
  2,W11,54,58
LIVE
  SOLU,VRR,,10,10,W13,1000
  CURR,1
  OUTP,W6,1,1
LIVE
  CURR,1
DYN
  INIT,W5,-119
  MOVE,101,2,0,-119
  TIME,,1
  OUTP,,.1
END

LIVE
  SOLU,MNR,,7,7,W13,200
  CURR,1
  OUTP,W6,2,1
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
December 1996

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE
SEADYN Analysis of a Tow Line for a High Altitude Towed Glider

5. FUNDING NUMBERS
WU–537–10–20
C–NAS3–27186

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER
E–10589

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

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR–202308

11. SUPPLEMENTARY NOTES

Project Manager, Lisa L. Kohout, Power Technology Division, NASA Lewis Research Center, organization code 5440, (216) 433–8004.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 07

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The concept of using a system, consisting of a tow aircraft, glider and tow line, which would enable subsonic flight at altitudinal subsonic flight at altitudes above 24 km (78 kft) has previously been investigated. The preliminary results from these studies seem encouraging. Under certain conditions these studies indicate the concept is feasible. However, the previous studies did not accurately take into account the forces acting on the tow line. Therefore in order to investigate the concept further a more detailed analysis was needed. The code that was selected was the SEADYN cable dynamics computer program which was developed at the Naval Facilities Engineering Service Center. The program is a finite element based structural analysis code that was developed over a period of 10 years. The results have been validated by the Navy in both laboratory and at actual sea conditions. This code was used to simulate arbitrarily-configured cable structures subjected to excitations encountered in real-world operations. The Navy's interest was mainly for modeling underwater tow lines, however the code is also usable for tow lines in air when the change in fluid properties is taken into account. For underwater applications the fluid properties are basically constant over the length of the tow line. For the tow aircraft/glider application the change in fluid properties is considerable along the length of the tow line. Therefore the code had to be modified in order to take into account the variation in atmospheric properties that would be encountered in this application. This modification consisted of adding a variable density to the fluid based on the altitude of the node being calculated. This change in the way the code handled the fluid density had no effect on the method of calculation or any other factor related to the codes validation.

14. SUBJECT TERMS
Tethering; Towed bodies; Numerical analysis; Finite element method

15. NUMBER OF PAGES
10

16. PRICE CODE
A02

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	