

# Natural Language Analysis and Machine Translation in Pilot - ATC Communication

**Boh Wasyliw\* & Douglas Clarke<sup>§</sup>**

\*De Montfort University, UK

<sup>§</sup>Cranfield University, UK

## Abstract

A significant factor in air accidents is "pilot error". Included in this category are errors in natural language communication between the pilot and air traffic control (ATC); errors possibly compounded by the use of English as a standard language for such communication. We concentrate on the likelihood of misunderstanding created by ambiguities in these messages. Often only a few seconds exist between the receipt of an ambiguous message and the subsequent incorrect action (potentially) leading to a fatal accident.

We consider the feasibility of filtering each spoken message through an "intelligent computer interface", testing for ambiguities and only transmitting those messages which are clear and unambiguous. Unclear, ambiguous messages should be "authenticated" before transmission.

The procedures for computer analysis would require not only sensitive speech recognition equipment but also complex software performing sophisticated linguistic analysis at the phonetic, syntactic, semantic and pragmatic levels. Analysis must also take place in "real time" so that both pilot and controller can receive warning that ambiguities exist in the last communication and corrective action taken in the short time available.

Consideration is also given to extending the system from the monolingual to multilingual level allowing pilot and controller each to think and speak in his own native tongue. The sophisticated language analysis is being extended to allow for appropriate disambiguated, bilingual machine translation.

## 1 Introduction

With speech-recognition facilities becoming increasingly available, and increasingly more versatile, the possibility of computer analysis and monitoring of spoken dialogue is now becoming a reality. Such analysis could be applied in a variety of different situations.

The discussion here is concerned specifically with the computer analysis of dialogue between pilot and air traffic controller (ATCr). A number of fatal aircraft accidents have occurred as a result of human error. Some of these are specifically a result of misunderstanding between the pilot and ATCr when communicating with each other in natural language, English (the international language of air transport communication), which is not necessarily their mother tongue.

Instances are the air crashes at Tenerife (Example 1, section 2.8 and the appendix), California (Example 2, section 2.8) and New York (Example 3, section 2.8).

The particular problem is that of using a computer

1. to locate any ambiguity or lack of clarity in that spoken dialogue;
2. to "highlight" this "immediately" so that any misunderstanding may be resolved in time before an otherwise actual accident occurs.

Our discussion is concerned with the first stage, also with any way in which the computer's warning message can help reduce the response - time in the second stage.

Clearly, the speed at which a computer can perform such analysing and monitoring is (literally) vital; a few seconds may be the only time left available before the pilot can avert an accident.

This short period of time will be made up of:

1. the time for the computer to perform the analysis and warn the pilot and ATCr;
2. the response-time of the pilot and ATCr to clarify the ambiguity  
and then
3. the time taken by the pilot to take any necessary avoiding action.

CLEARLY, EACH OF THESE STAGES HAS TO BE KEPT TO A MINIMUM TIME.

It should be noted that the techniques developed may also be used in other applications in which spoken dialogue is used.

The central problem that we have to focus on is that of locating and resolving ambiguities. This problem has occupied researchers in Natural Language Processing (NLP), and particularly Machine Translation (MT), for many years. However, this problem has been concerned in the past with disambiguation in the traditional medium of written/printed text.

The use of spoken dialogue introduces a whole variety of additional characteristics which also have to be considered in the disambiguation process.

## 2 Ambiguity

There are many kinds of ambiguity. The ambiguities we are concerned with fall into one of the following categories:

- LEXICAL AMBIGUITY
- SYNTACTIC AMBIGUITY
- SEMANTIC AMBIGUITY
- PRAGMATIC AMBIGUITY
- CULTURAL AMBIGUITY
- PHONETIC AMBIGUITY

although many expressions will each involve a combination of several of these.

## 2.1 Lexical Ambiguity

Examples of lexical ambiguities are the words "bank" and "right" in the statement:

### **Bank in the right direction.**

Each of these two words can have more than one meaning. However, at least one meaning of the word "bank" is unlikely to occur in the vocabulary of air transport. Care, nevertheless, must still be taken in the use of specialist vocabularies. For instance, in an air-accident involving injuries to people, the word "airways" becomes lexically ambiguous since this scenario now includes both the medical and the aeronautical contexts. This is also a clear instance of pragmatic ambiguity (for which, see section 2.4).

It should also be noted that, not only could a word have more than one lexical meaning, it could also fall into one or other of a number of grammatical categories in which latter case it is referred to here as a homomorph. For example, "bank" could be a noun (N) or verb (V). This gives rise to another category of ambiguity, instanced by the statements:

#### 1. **Time flies.**

N      V  
V      N  
(i.e. sentence in each meaning),

#### 2. **The old train in the station**

(noun-phrase in one meaning, sentence in the other).

#### 3. **The old man boats in the river.**

(sentence in either meaning).

## 2.2 Syntactic Ambiguity

An example of a syntactic ambiguity is the sentence

### **He located the plane with the radar equipment.**

which has (at least) two different sentence structures and, accordingly, two different meanings. That this sentence has two distinct structures may be readily demonstrated. By using (some of) the rewrite rules for English, and substituting the left side for the right side of each rule as appropriate, the sentence may be reduced to the single category S in two different ways.

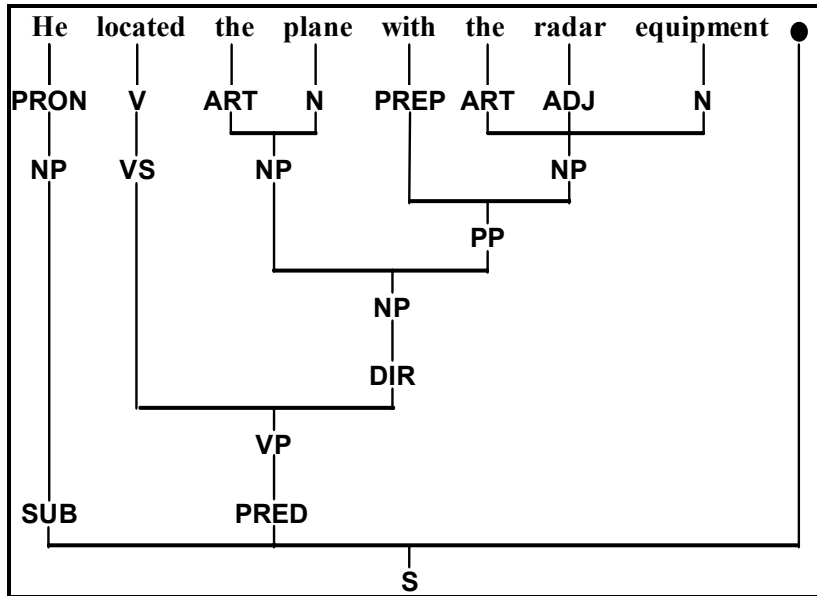


Figure 23 - 1: Syntactic Analysis 1

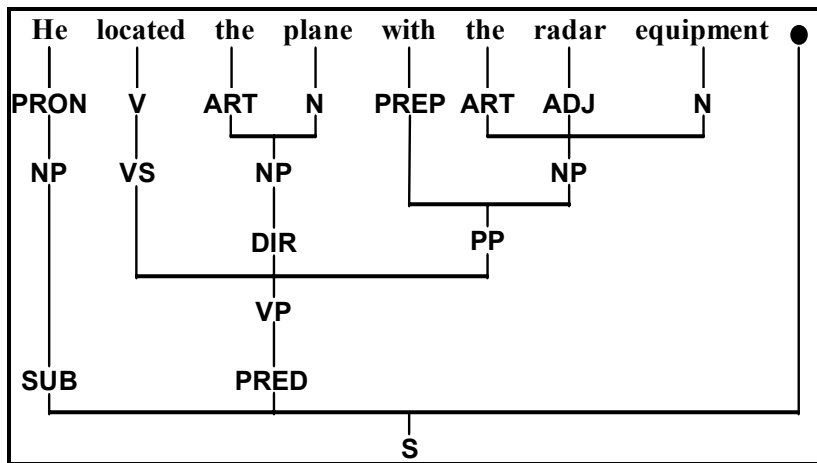


Figure 23 - 2: Syntactic Analysis 2

2.2.1 Computerised Dictionary

Entries include:

| <u>Word</u> | <u>Grammatical Category</u> |
|-------------|-----------------------------|
| equipment   | N                           |
| he          | PRON                        |
| locate      | V                           |
| plane       | N                           |
| radar       | ADJ                         |
| the         | ART                         |
| with        | PREP                        |

Table 23 - 1: Computerised Dictionary

### 2.2.2 Rewrite Rules

#### Entries include:

|      |   |                |
|------|---|----------------|
| S    | → | SUB + PRED + ● |
| SUB  | → | NP             |
| PRED | → | VP             |
| VP   | → | VS+ DIR        |
| VP   | → | VS + DIR + PP  |
| DIR  | → | NP             |
| VS   | → | V              |
| PP   | → | PREP + NP      |
| NP   | → | PRON           |
| NP   | → | ART + N        |
| NP   | → | ART + ADJ + N  |
| NP   | → | NP+ PP         |

where + means "succeeded by".

**Table 23 - 2: Rewrite Rules**

One structure, represented by the tree-diagram in figure 23 - 1, corresponds with the meaning that the plane had the radar equipment. i.e. the prepositional phrase "with the radar equipment" is being used as an adjectival phrase qualifying "plane". The other structure, represented by the tree-diagram in figure 23 - 2, corresponds with the meaning that the locating was being done with radar equipment. i.e. the prepositional phrase "with the radar equipment" is here being used as an adverbial phrase qualifying the verb "located". The computer analysis of the sentence structure, corresponding to the left-for-right substitution of each rewrite rule when appropriate, would become more involved if account were taken of the consideration that e.g. "plane" is a homomorph.

Thus, the computerised dictionary might contain three entries for "plane", i.e.

|       |     |
|-------|-----|
| plane | N   |
| plane | V   |
| plane | ADJ |

Each possibility would then have to be examined in the computer analysis.

[NOTE: There could also be additional entries for the different lexical meanings of the word "plane"].

### 2.3 Semantic Ambiguity

An example of a semantic ambiguity is the phrase:

#### **blown up**

which, depending on the context, could mean:

blown to a higher altitude (by the wind);  
detonated;  
inflated (as a balloon);  
enlarged (as a photograph);

or

taken out of proportion (as an argument).

Nevertheless, the category of semantic ambiguity is something of a linguistic tautology; any ambiguity, as it involves a choice of meaning, must be regarded as a semantic ambiguity. Thus, all the other categories of ambiguity referred to here can be regarded as being embraced within the all-inclusive category of semantic ambiguity.

## 2.4 Pragmatic Ambiguity

A paper on aviation medicine reported that it was found that a pilot loses height when ejected from an aircraft. Did the author of that paper mean 'height' in the sense of altitude or 'height' in the sense of the pilot's 'tallness'?

This lexical ambiguity can nevertheless also be regarded as a pragmatic ambiguity since it does depend on the reader's understanding of the use of language to discern what the author is intending to convey. That anything, or anyone, loses altitude under gravity is common knowledge, i.e. is unremarkable. In other words, it is unlikely that the author would be making a remark with this intended meaning. On a pragmatic basis, therefore, it is the other meaning which can be presumed that the author is intending. (This of course is also substantiated by the consideration that this ambiguity appeared in a paper on aviation medicine which is therefore more likely to be discussing the pilot's physiology).

## 2.5 Cultural Ambiguity

In the statement:

**Mary McDonald told the pilot her flight would be late.**

the pronoun 'her' could refer anaphorically to Mary McDonald or to the pilot. Whether this is considered an ambiguity depends on the cultural context in which the statement is made. In a Gulf Air Flight or a PIA flight, for example, this utterance would not be regarded as ambiguous; 'her' could not refer anaphorically to the pilot. In other airlines, where women are employed as pilots, the ambiguity in the anaphoric reference becomes possible. (Ambiguity could, of course also arise if there is the possibility of an anaphoric reference of 'her' to someone named in the preceding sentence(s)).

A different kind of cultural ambiguity can also arise in which a statement is assumed to have one unambiguous meaning in one cultural context but another unambiguous meaning in another cultural context.

Such ambiguities as those discussed above, found in written or printed text, are equally as likely to occur in spoken mode. However, in addition, in speech, there is a range of other features which can also lead to ambiguities. These too will have to be catered for in the proposed system.

## 2.6 Phonetic Ambiguity

(NOTE: in the following discussion

1. stress marks have been omitted from the phonetic representations;
2. spaces do not normally occur between words in typical continuous speech, (cf. 2.6.2 below)).

Perhaps the first kind of ambiguity one thinks of in using spoken language is the existence of homophones. The problem of the arising ambiguity occurs, for example, in the sentence (whose phonetic representation is)

**ju:z ðə tɜ:mml m ðə raɪt məʊd**

in which 'raɪt' can represent either of the homophones

'right' or 'write'

The sentence is meaningful with either of these words, and is thus ambiguous.

Homophones can occur in the same sentence e.g.

**ðeər ðeər ðeər əʊn bɒsɪz**

where each 'ðeər' can represent any one of the homophones

there (ADV)  
 their (ADJ)  
 or  
 they're (PRON + V).  
 (they are)

Assuming each of these words occurs once in the sentence, then there are six possible strings of grammatical categories from which to determine, using rewrite rules, which correspond to valid sentence structure(s).

This computer analysis can be achieved using left-for-right substitution in rewrite rules, as described above.

In another example,

**hi: tʊ: hæz hæd tʊ: tʊ: meni drɪŋks**

each occurrence of the phoneme 'tʊ:' could correspond with any one of the words

to (PREP)  
 two (ADJ)  
 or  
 too (ADV)

Analysis would show that this sentence has a valid structure with two occurrences of "too", one of "two" and none of "to".

### 2.6.1 Diction

Lack of good diction is another problem, e.g. when someone does not enunciate the final consonant of a word. For example, a customer may ask a building society cashier if he can draw out fiftee' pounds. Did he mean "fifteen" or "fifty"? (One wonders what will happen in the future when there is voice input to cash machines).

This problem is overcome in airline communication, where pilots and ATCr's are recommended to say each digit e.g. "five zero" for fifty. There is then the danger, however, that each digit may be confused with any of its homophones e.g.

**one** with **won**  
**two** with **too**  
 or **to**  
**four** with **for**  
**eight** with **ate**  
**nine** with **nein**

### 2.6.2 Merging of Words

Whenever words are usually separated by spaces in written or printed mode, they usually become merged in spoken mode. Consider, for example, this message from a pilot to the ground-control of the airfield he's approaching:

**ɑrhævtwentisiksɛnlɜzɔnbɔ:d...**

**...Please have transport ready for them when I land.**

How many sailors? and what sort of transport? ... ambulances?

The problem here is that the phoneme at the beginning of one word (e.g. sailors) might (or might not) also occur at the end of the preceding word (e.g. sick or six), with the two phonemes merging. This feature should be catered for in the analysis of the pilot's message when input to the monitoring computer, in order that the ambiguity can be resolved.

### 2.6.3 Phoneme Modification

Another feature which should also be catered for is the possible modification of the initial or final phoneme of a word in virtue of (the phonemes in) the adjacent word(s). For example, the statement:

**The ground is deeper on the other side.**

may sound like:

**The ground is steeper on the other side.**

the dental "d" being pronounced as the dental "t".

### 2.6.4 Speech Cognition

Not only are there problems with the possible "distortion" of a message as it originates with the speaker, there may also be problems with the "distortion" of a message when it is heard by a listener. In other words, a listener may take in the message according to what s/he expects it to be rather than the message that the ear actually receives. This is parallel to a phenomenon which cognitive psychologists also describe about reading.

A recent radio report referred to some air force pilots who were engaged in some high-altitude exercises. When they landed, it was thought that the report said that they took part in a **deep breathing exercise** (.because they had been at high altitude?). What actually was said was that they took part in a **de-briefing exercise**. Thus there was confusion by the listener between the fricatives "f" and "th" and also between the labials "p" and "b". Indeed, the labials "p" and "b" in **deep breathing exercise** can sometimes be merged by a speaker as the single labial "b".

## 2.7 Ellipsis

One characteristic of human dialogue is the use of ellipsis.

Ellipsis can occur within a single sentence. It arises when part of (what was) a well-structured sentence is omitted but is assumed to be understood by the reader/listener, because it is a repetition of a previous word/phrase in the sentence.

An example of ellipsis in a single sentence is:

**The pilot is having chicken curry and the co-pilot trout.**

Because the sentence is ill-structured at the surface level, syntactic analysis of such a sentence would require:

- the identification of the gap,
- the identification, by matching, of the missing word/phrase,
- the re-insertion, in the gap, of this missing word/phrase.

Ellipsis can also occur in dialogue, in particular in the answer to someone's question. For example, the answer to the question

**How many passengers have you on board?**

could be

**We have 295 passengers.**

or even

**295 passengers.**

or even just

**295.**

However, the last two answers could not be parsed as a sentence if tested with a syntax analyser.

How can this last problem be overcome?

One approach is to transform the given question into the corresponding declarative statement. This should then be the form of the full answer, into which the shortened answer can be inserted, where appropriate. It should then be possible for the answer to be parsed, as a sentence, by the syntax analyser.

In addition to its use in Pilot-ATC communication, the algorithm for building up the full response, and thereby analysing the dialogue, may also be usefully used in a wide range of other contexts.

## 2.8 Examples From Pilot-ATC Communications

Example 1: Los Rodeos, Tenerife, 27 March 1977

**Spoken phrase:** "at takeoff"  
**Meanings:** 1. in the process of taking off  
 2. at the takeoff point  
**Result:** Plane collides with another aircraft on runway,  
**583 dead**

Example 2: John Wayne Orange County Airport, Santa Ana, California, 17 February 1981

**Spoken phrase:** "hold"  
**Meanings:** 1. stop- *normal practice*  
 2. continue- *idiomatic English*  
**Result:** Plane lands with gear retracted,  
**34 injured, plane destroyed**

Example 3: Cove Neck Airport, N.Y., 25 January 1990

**Spoken phrase:** "running out of fuel"  
*a non-standard phrase*  
**Should have used phrase:** "emergency"

**Result:** *which is standard procedure*  
Plane ran out of fuel and crashed,  
**73/159 dead; including 3 crew**

Example 4a: Semantic Ambiguity

**Spoken phrase:** "converging traffic **descend** to 6000 feet"

**Meanings:**

1. all traffic descend
2. converging traffic descend
3. that plane descend

Example 4b: Syntactic Ambiguity

**Spoken phrase:** "converging traffic descend **6000 feet**"

**Meanings:**

1. by 6000 feet
2. to 6000 feet

Example 5: Lexical Ambiguities

**Spoken phrase:** "PD"

**Meanings:**

1. **P**ilot's **D**iscretion
2. **P**rofile **D**escent

Example 6: Pragmatic Ambiguity

**Spoken phrase:** "I've got it"

**Meanings:**

1. I see it
2. I understand
3. I have the controls
- ⋮

Example 7: Pragmatic Ambiguity

**Spoken phrase:** "go ahead"

**Meanings:**

1. continue
2. speak now
3. request granted
4. proceed forwards
- ⋮

Example 8: Phonetic Ambiguity

**Spoken phrase:** "**last** of power"  
meaning *cut your power*

**Heard as:** "**blast** of power"  
meaning *open the throttle*

Example 9: Phonetic Ambiguity

**Spoken phrase:** "pass to the **left** of the tower"

**Heard as:** "pass to the **west** of the tower"

Example 10: Pragmatic Ambiguity

**Spoken phrase:** "traffic at 10, o'clock, 3 miles,  
level at 6000 feet to pass under you"

**Meanings:**

1. descend to, and level off at, 6000 feet
2. traffic is level at 6000 feet, stay put!

Example 11a: Phonetic Ambiguity

**Spoken phrase:** "cleared to seven"

**Meanings:**

cleared

1. for runway 27
2. to runway 7

Example 11b: Phonetic Ambiguity

**Spoken phrase:** "climb two five zero"

**Meanings:**

1. climb to 25000 feet
2. climb to 5000 feet

Example 11c: Phonetic Ambiguity

**Spoken phrase:** "descend two four zero zero"

**Meanings:**

1. descend to 2400 feet
2. descend to 400 feet

## 2.9 Further Examples

Example 12: *Flying planes* can be dangerous!

**Spoken phrase:** *Flying planes* can be dangerous!

☹ ? what!

1. Planes that fly can be dangerous?  
safe when stationary!
2. Being a pilot ...?  
be a train driver!
3. Travelling by plane ...?  
go by ship!
4. Misuse of woodworking tools ...?  
? \*\*@\$%\*!

☹ HELP!

Example 13: Semantic Ambiguity

**Spoken phrase:** "I don't think(,) I know."

**Spoken phrase:** "The stewardess stood by the door and called the passengers(') names as they arrived."

Example 14 : How Many Ambiguities?

**Spoken phrase:** "She told the pilot her flight would be late."

☹ Whose flight?:

1. her own
2. the pilot's
3. another pilot's
4. a passenger's

## 2.10 Summary

The table below identifies the main types of ambiguity contained in the examples above. This reinforces our assertion that many statements may each have more than one type of ambiguity associated with it.

| Example | Types of Ambiguity |
|---------|--------------------|
| 1       | L, SE              |
| 2       | L, PR              |
| 3       | C, PR              |
| 4a      | PR, SE             |
| 4b      | PR, SE, SY         |
| 5       | L                  |
| 6       | C, L, PR, SE       |
| 7       | C, L, PR, SE       |
| 8       | PH                 |
| 9       | PH                 |
| 10      | PR                 |
| 11a     | PH                 |
| 11b     | PH, SY             |
| 11c     | PH, SY             |
| 12      | L, PR, SE, SY      |
| 13      | PH, SE, SY         |
| 14      | PH, SE, SY         |
| 15      | C, SE              |

Ambiguities:

- C - cultural language differences
- L - lexical vocabulary
- PH - phonetic sound
- PR - pragmatic context
- SE - semantic meaning
- SY - syntactic grammar

**Table 23 - 3: Summary of Ambiguities in Examples 1 to 14**

## 3 The Problem of Timing

In the case of communication between a pilot and ATCr, the computer analysis and monitoring of their dialogue has to be fast - as fast as possible. Then, should any ambiguity occur, this can be relayed as soon as possible to the pilot and ATCr, so that the pilot has as much time as possible to take any action necessary to avoid an accident.

**How can the computer analysis and monitoring be designed to be as fast as possible?**

Two of the principal ways are:

- use of parallel computing,
- use of a fast syntax analyser.

### 3.1 Parallel Computing

For example, semantic analysis may be performed in parallel to syntactic analysis, instead of in sequence - which latter has often been the case in traditional NLP

### 3.2 Fast Syntax Analyser

The syntax analyser referred to above, which uses rewrite rules, requires the whole sentence to be read in before analysis can commence. Also, there are upwards of 1500 rewrite rules for the English language.

A "left-to-right" parser would be preferable, so that parsing can commence as soon as the first word of the sentence is spoken, and will be almost complete as soon as the last word is spoken. Such "left-to-right" parsing can be achieved using an ATN (augmented transition network). Consider for example, the sentence

S1: Cats like Felix.

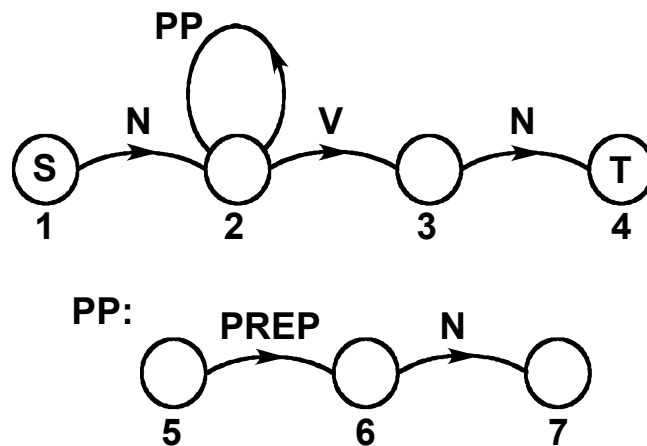
and the sentence

S2: Cats like Felix like fish.

The corresponding entries in the computerised dictionary are:

|       |           |
|-------|-----------|
| Cat   | N         |
| Felix | N         |
| fish  | N         |
| like  | V or PREP |

Part of the ATN which will cater for these sentences is



where S and T are start and end nodes of a valid (i.e. well structured) sentence.

Tracing possible paths for S1: 1 - 2/5 - 6 - 7/2 (which is not well-structured)

or 1 - 2 - 3 - 4 (which is well-structured).

Tracing possible paths for S2: 1 - 2/5 - 6 - 7/2 - 3 - 4 (which is well-structured).

As soon as the first word of a sentence is input, possible paths may start to be traced. As further words are input, some of these paths may be discounted/deleted. After the last word has been input, there will, it is hoped, be one path remaining or, possibly, two or more, in which latter case there is a syntactic ambiguity.

One of the features of spoken communication, however, is that perfectly structured sentences do not always occur<sup>1</sup>.

Thus, for example,

**How many passengers have you on board?**

is transformed, by program, into

**I/We have ..... passengers on board.**

into which can be inserted, or 'merged', e.g. **295 passengers** to give

**I/We have 295 passengers on board.**

(See section 2.7 above).

NOTE:

In view of the need to minimise the total computational time, the structure of a question, traced out in the ATN, can be transformed into the structure of the expected answer in the ATN e.g. during the time the "respondent" is giving his shortened form of the answer.

#### **4 A Proposed Solution**

If the analysis of a message by either pilot or ATCr indicates that it is ambiguous, this should be relayed to them, informing them of both, or all, the possible interpretations and asking the speaker which meaning he intended.

This may be better done in written mode on their screens (but also with warning buzzer) since they may already be speaking.

For example, suppose this procedure had been available at the time of, or more precisely 41 seconds before (!), the air crash at Los Rodeos Airport, on 27 March 1977, (example 1 section 2.8 and the appendix), in which 583 people died. Then, immediately after the pilot made the ambiguous statement "...at take off..." there would have appeared on the computer screens of the pilot and ATCr, this dialogue:

**Pilot, by 'at take off' do you mean:**

**1) You are now in the process of taking off**

**or**

**2) You are now at the point of take off**

**?**

**→**

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<sup>1</sup> A research group at Saarbrücken University, who presented a paper at this conference, are tackling this problem by analysing extensive recordings of human dialogue to find any patterns.

At this stage the pilot would have input 1 or 2, according to the meaning he intended. His response would also have appeared on the screen of the ATCr, so the ATCr would also have known the meaning the pilot intended. The ATCr could then have immediately informed the pilot what avoiding action he should take.

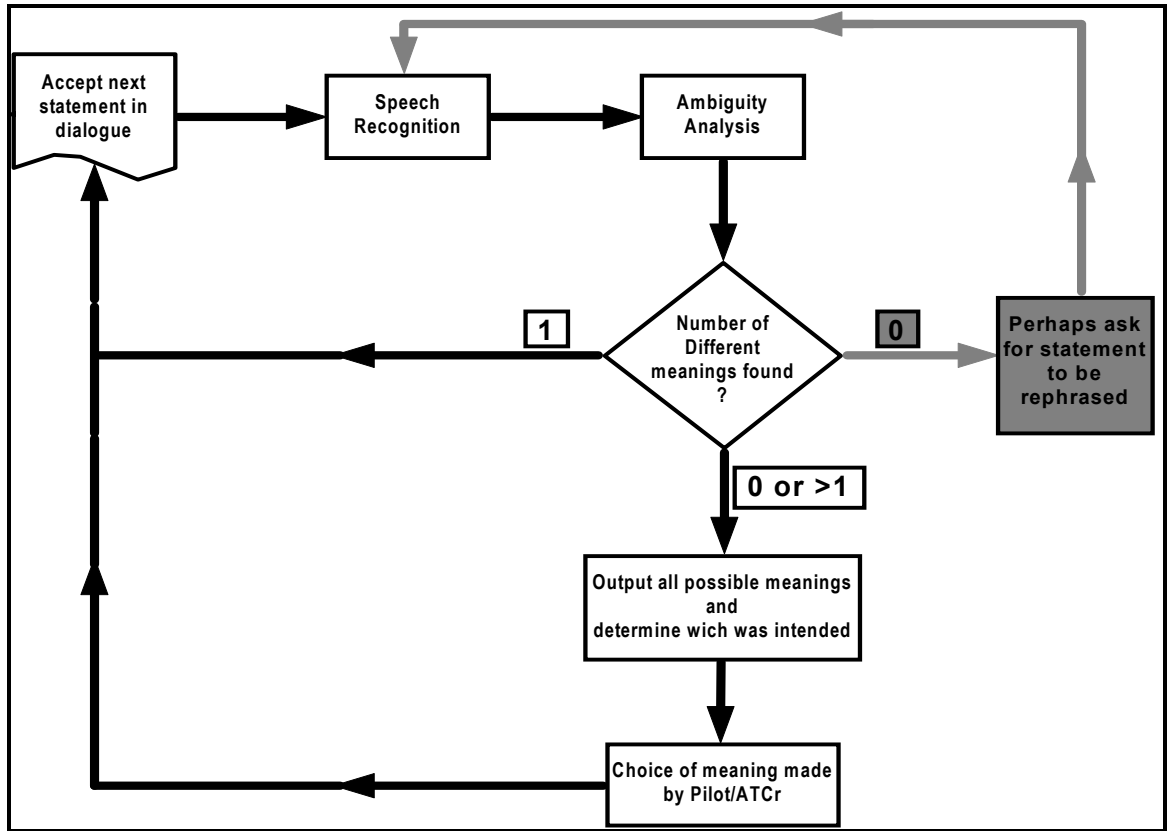


Figure 23 - 3: Proposed Solution — An Overview

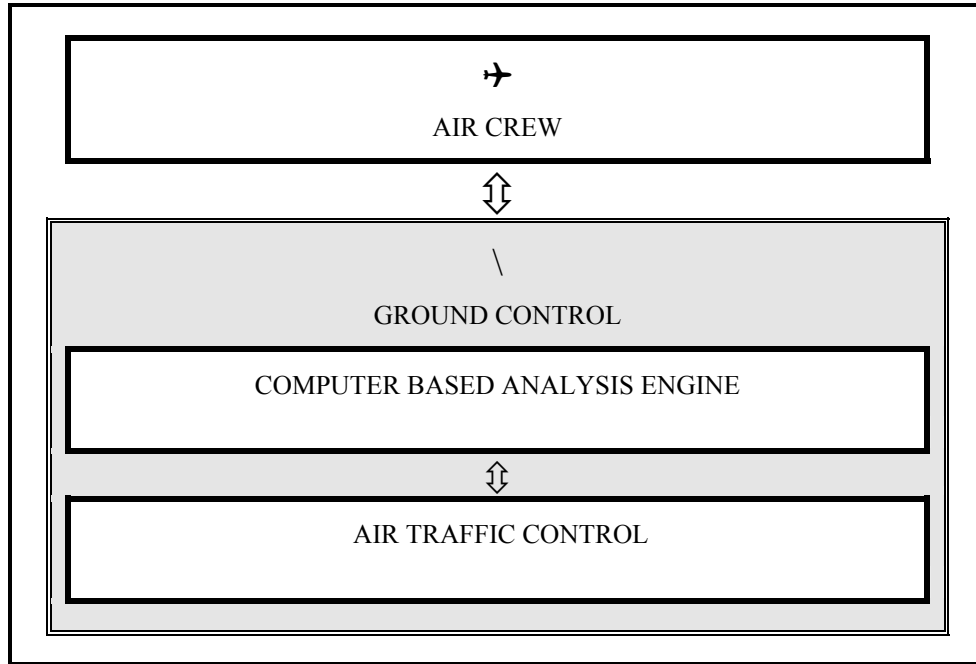


Figure 23 - 4: Proposed Solution - Outer Level

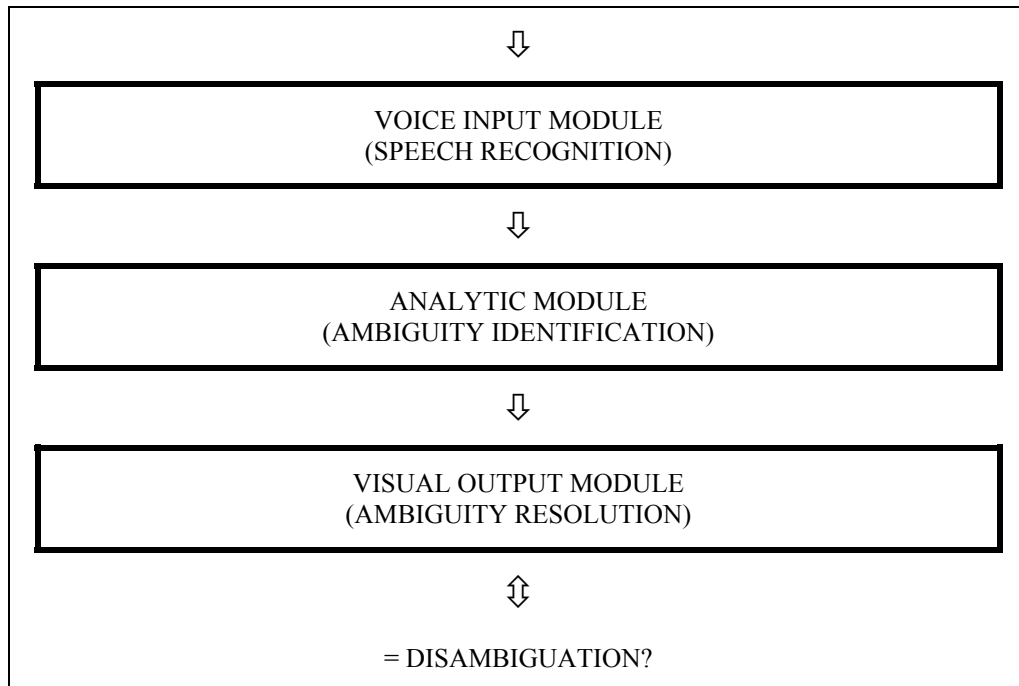


Figure 23 - 5: Proposed Solution - Level 2, Computer Based Analysis Engine

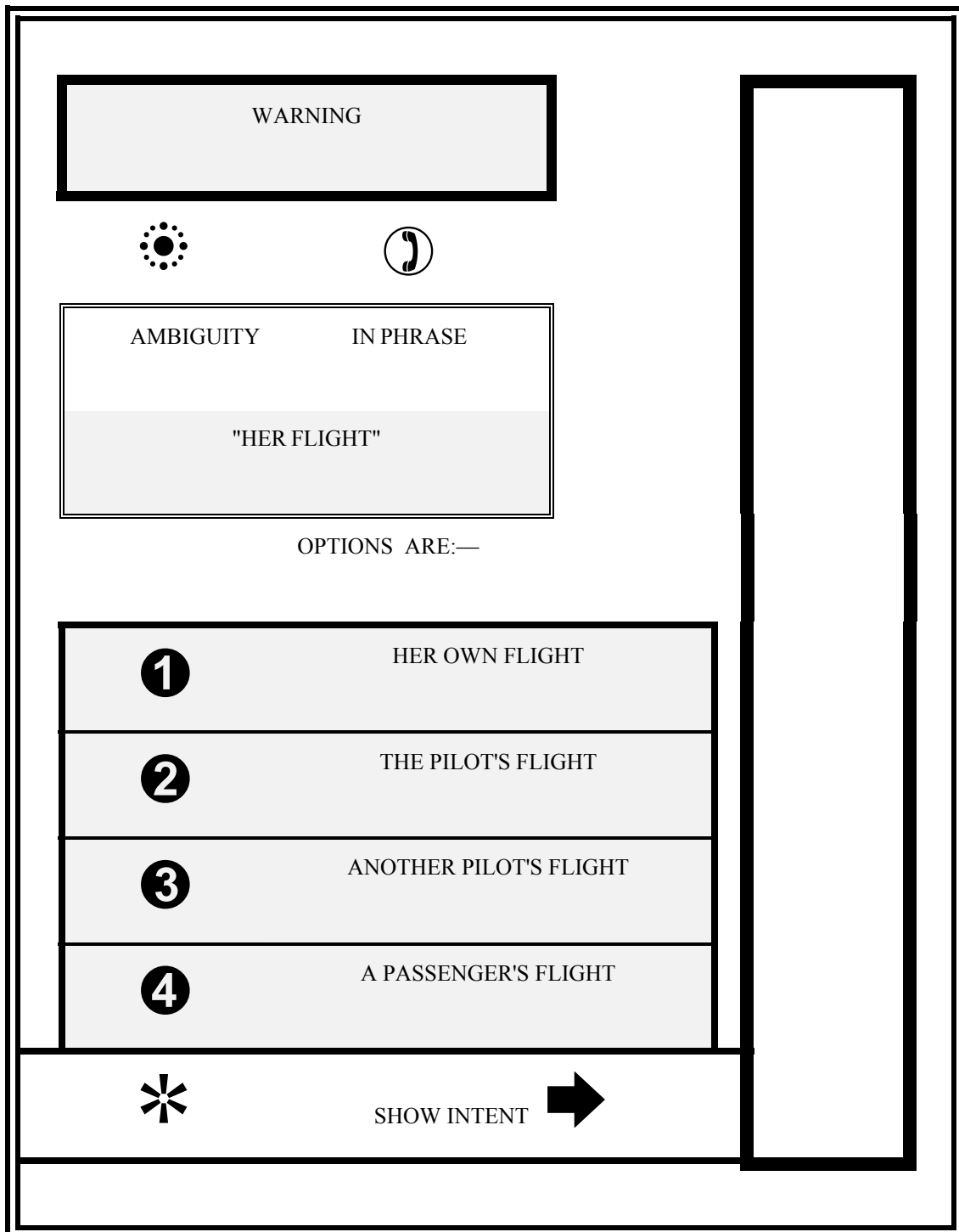
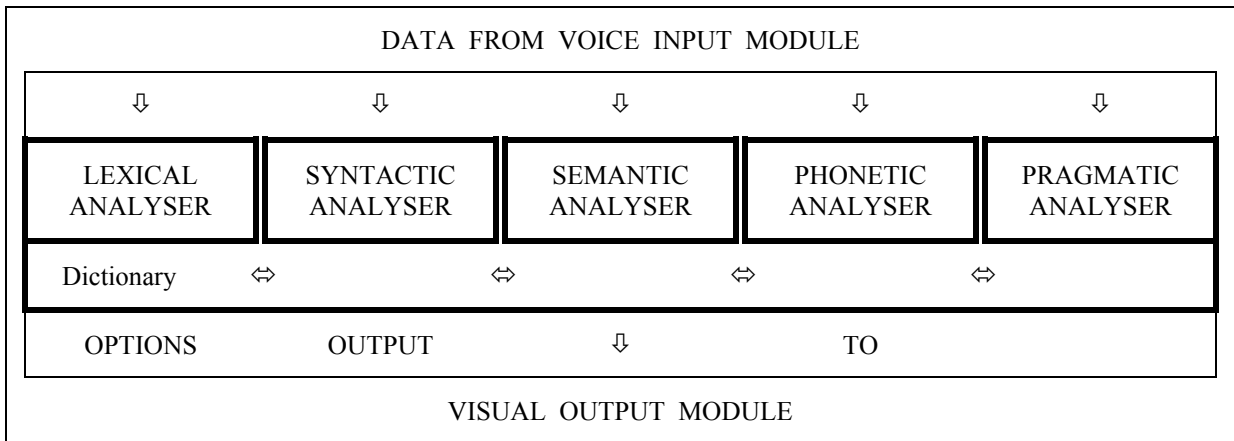


Figure 23 - 6: Proposed Solution - Level 2, Possible Visual Output Screen



Required speed to be achieved by the use of:

- Parallel processing
- Augmented transition networks
- Neural nets
- Fuzzy logic circuits

**Figure 23 - 7: Proposed Solution - Level 3, Analytic Module**

## 5 An Interim Solution

While the proposed solution is being developed we suggest an interim solution which should be easily and quickly implemented.

This system is composed of a visual display board in the cockpit and duplicated at ATC which will highlight a summary of the intended message and so decrease the chance of misunderstandings occurring.

For example the screen below (Figure 23 - 8) confirms an emergency and requests the pilot to descend to 20 000 feet. As a further safeguard the plane's flight identification number would be displayed. The pilot would be alerted by both audio and visual signals.

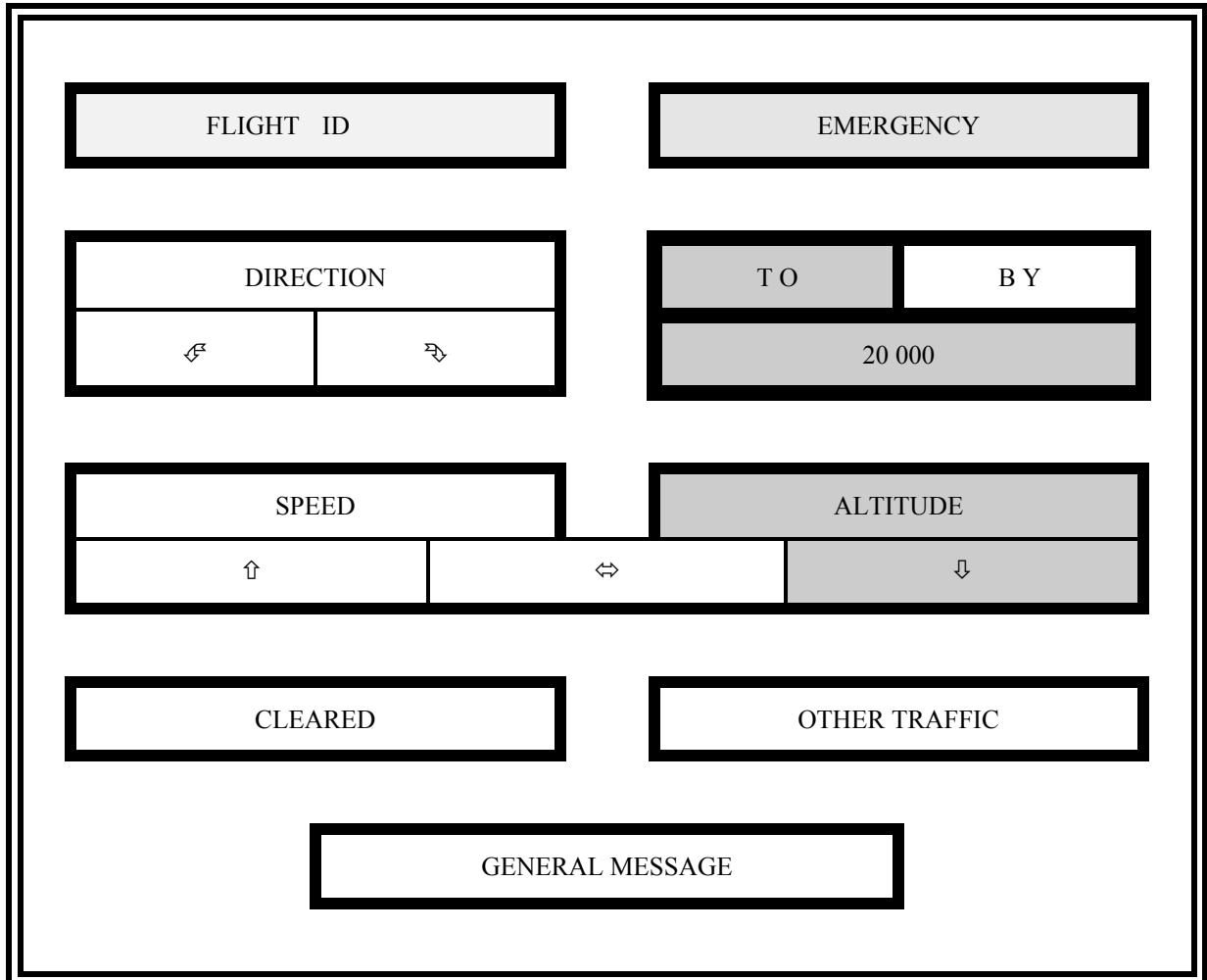


Figure 23 - 8: Interim Solution - Possible Screen

## 6 Testing the System

### 6.1 Problems:

- Ambiguities not identified
- Ambiguities incompletely resolved
- System not fast enough
- Slow thinking/reaction time

One problem that may well present itself is the sheer number of ambiguities that might occur in a dialogue. More ambiguities occur in conversation than many of us realise. Even a sentence such as;

The cat sat on the mat.

might look (or sound) quite innocuous but it nevertheless is ambiguous.

The problem here is that, if the pilot and ATCr are alerted to numerous ambiguities, many of which are quite 'harmless', a 'cry-wolf' attitude may develop whereby they just ignore the warnings, even the serious warnings.

## 6.2 R&D

The difficulties mentioned above may be diminished by having many of the (types of) harmless ambiguities, occurring during trial or training sessions, pointed out by experienced pilots. Then it can be arranged that:

1. such (types of) ambiguities are filtered out of the proposed monitoring system
- and
2. trainee pilots and ATCr's are trained in a style of dialogue (already quite stylised) which will significantly reduce the number of such harmless ambiguities.

## 6.3 Flight simulators

Finally, the computerised analysis and monitoring system could be, crucially, tested by re-enacting on an aircraft simulator the events leading up to each of the crashes, e.g. in Tenerife, (example 1 section 2.8 and the appendix), and in Washington.

This time, however, the computer monitoring system will be incorporated.

It can then be determined

1. whether the monitoring system discovered the ambiguity which previously led to the crash
2. whether it discovered it fast enough for the pilot in the simulator to take avoiding action to prevent the crash.

## 7 Enhancements to the System

One air-crash arose out of misunderstanding, by the Spanish pilot, of the English ATCr.

One enhancement is to make available MT modules, one for each language pair, so that the mother-tongue, could be "plugged-in" to the system.

The pilot would then receive messages in the language he best understands.

Given that ambiguities and other misunderstandings can arise when the mother-tongue of both pilot and ATCr is English (the international language of air communication), how much more likely are such misunderstandings to arise when the mother-tongues of either or both are not English? Clearly this is a further considerable problem. At least one air accident is believed to have resulted from this problem.

This particular problem can be largely overcome by the incorporation of a machine translation (MT) package

- or, rather, two MT packages.

This latter would be the case when both the pilot and ATCr are non-native-English speakers, but with different mother-tongues.

In the scheme proposed here, the pilot would 'plug-in' the E to L<sub>P</sub> (English to pilot's native language) MT module into the computer monitoring system. Also, the ATCr would have the E to L<sub>A</sub> (English to ATCr's native language) MT module plugged into the monitoring system.

Had such an enhanced system been available at the time of the Tenerife air crash on 27 March 1977, (example 1 section 2.8 and the appendix), then, appearing on the screen of the pilot (here assumed to be German), would have been (alongside the above equivalent dialogue in English):

Flugzeugführer, meinen Sie mit 'at take off':

- 1. Sie sind jetzt dabei abzuheben**  
**oder**  
**2) Sie sind jetzt am Startpunkt**  
 ?  
 →

- At this juncture, the pilot would input the answer 1 or 2 according to the meaning he intended.

Assuming the ATCr is Spanish-speaking, the corresponding dialogue in Spanish would appear on his/her screen (also alongside the same dialogue in English) as:

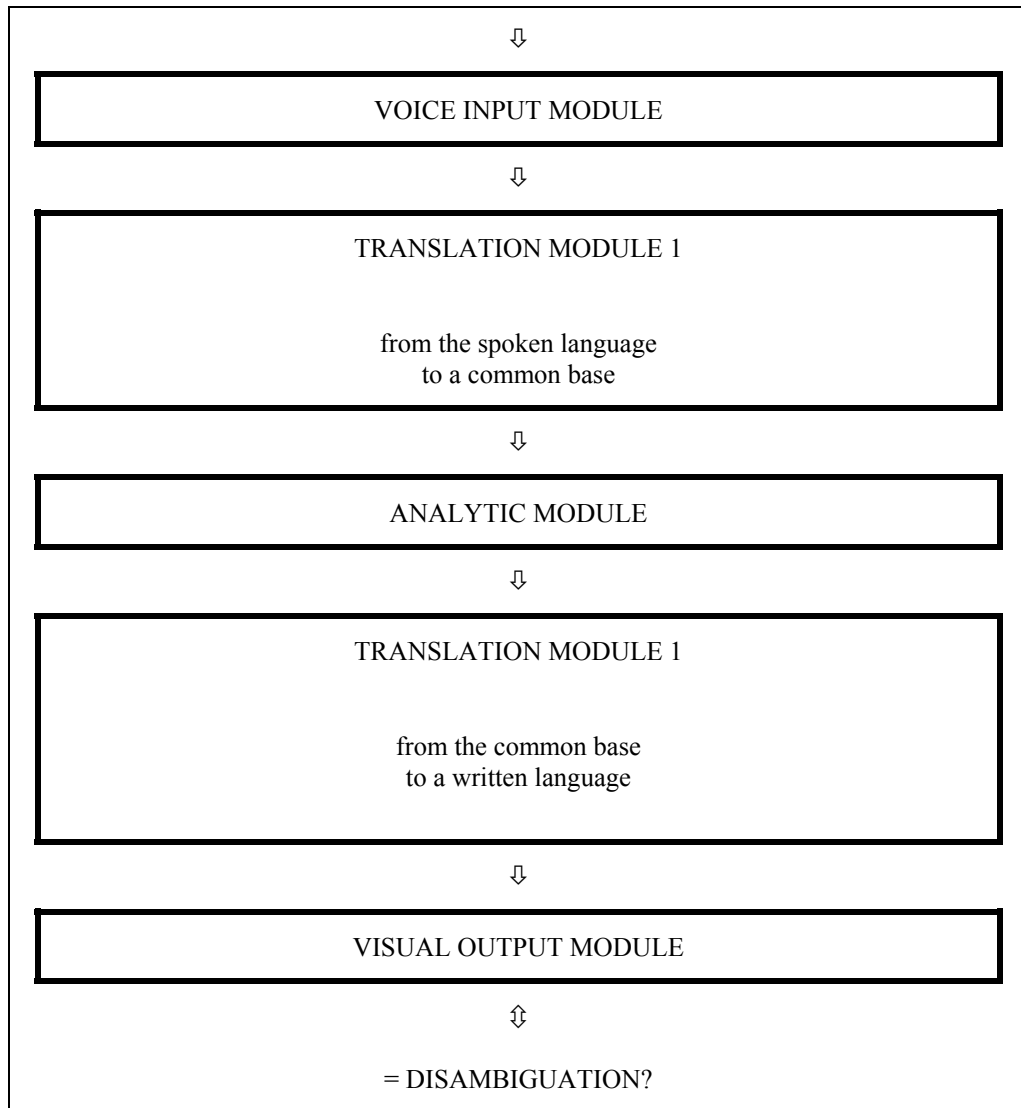
Piloto, para 'at take off' usted quiere decir que:

- 1. Usted esta ahora en el proceso de despegar**  
 o  
**2. Usted esta ahora en el punto de despegue**  
 ?  
 →

Thus the ATCr would also be made aware of the ambiguity/misunderstanding. Also, s/he would see on the ATCr screen, the same response (1 or else 2) input by the pilot and therefore be aware of the meaning the pilot actually intended.

If such an enhancement were available, it would have to be ensured that the machine translation, like the rest of the computing procedure, be performed as fast as possible. The analysis of the English having already been accomplished, however, this machine translation procedure should be relatively fast.

The advantage of such an enhancement is that, in a time of stress, the pilot and ATCr would more readily assimilate the crisis situation if it be expressed in their own languages rather than in English with which they would not be so familiar.



**Figure 23 - 9: Solution: An Extension**

## 8 Other Applications

Other applications of the system could be:

- International telephone calls
- Television interviews
- European Parliament
- Ambiguity-checker for a speech input word-processor.
- Diplomacy
- NATO, UN, EEC etc.
- Military
- Conferences
- Telephone
- TV — “on the fly” dubbing
- Personal

## Appendix

### Transcript of Example 1

1705:44.6 KLM 4805: The KLM *four eight zero five* is now ready for takeoff and we are waiting for our ATC clearance (1705:50.77).

1705:53.41 Tower: KLM *eight seven zero five* you are cleared to the Papa Beacon, climb to and maintain flight level nine zero, right turn after takeoff, proceed with heading four zero until intercepting the two five radial from Las Palmas VOR (1706:08.09).

1706:09.61 KLM 4805: Ah-roger sir, we are cleared to the Papa Beacon, flight level nine zero until intercepting the three two five. We are now at takeoff<sup>1</sup> (1706:17.79).

1706:18.19 Tower OK...Stand by for takeoff, I will call you (1706:21.79).

[Note: A squeal starts at 1706:19.39 and ends at 1706:22.06.]

[PAA: And we're still taxi-ing down the runway the Clipper one seven three six (1706:23.06).]

1706:21.92 PAA: Clipper one seven three six (1706:23.39).

1706:25.47 Tower: Ah - Papa Alpha one seven three six report the runway clear (1706:28.89).

1706:29.59 PAA: OK, will report when we're clear (1706:30.69).

1706:31.69 Tower: Thank you.

1706:50 COLLISION: KLM on takeoff run collides with PAA on ground.

NOTE that only 31 seconds elapsed between the time the ambiguous phrase was uttered (1706:18.19) and the time the collision occurred (1706:50).

## References

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- O'Connor, J. D., *Phonetics*, Penguin Books, London, England, 1973, ISBN: 0140-21560-3
- Woods, W. A., *Transition Network Grammars for natural Language Analysis*, Comm. ACM, 13-10, Oct 1992.

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<sup>1</sup> ATCr - waiting at the take-off point

PILOT - already on the take-off roll