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Probabilities for Severe and Fatal Injuries in General Aviation Accidents

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Although accident rates in general aviation have been published, probabilities for sustaining severe or fatal injuries have not yet been sufficiently evaluated. The aim of this study was to develop probabilities for severe and/or fatal injuries in general aviation accidents. Using official German data, the total number of general aviation accidents and severely or fatally injured persons were obtained from 1993 to 2007. The analysis focused on both the average number of injured and average number of killed persons and the probabilities of sustaining severe or fatal injuries. SPSS® was used for statistical analysis with $p < 0.05$. $N = 5259$ general aviation accidents were analyzed. Most accidents occurred in the categories for gliders ($n = 1930$, 36.7%) and single-engine pistons (less than 2 tons; $n = 1929$, 36.7%). The highest probabilities of sustaining severe injury were found for hot-air balloons (72.9%), gliders (15.2%), and helicopters (12.0%). The highest probabilities of sustaining fatal injury were found for aircraft of 2–5.7 tons (23.1%), helicopters (17.1%), and aircraft less than 2 tons (14.0%). Because of a lack of common denominator data in general aviation, the development of accident statistics is complicated, if not entirely impossible. Probabilities for severe and fatal injuries that could be expected should an accident occur (conditional probabilities) were calculated. These data facilitate the understanding and improvement of aviation safety.

Introduction

THERE are approximately 200–300 general aviation (GA) accidents in Germany per year [1–3], resulting in approximately 50 killed or severely injured occupants. Usually, 85% of these accidents involve gliders or single-engine piston aircraft that are generally flown by owner pilots or defined groups (e.g., flying clubs and shared ownership) and for recreational purposes [1]. About 10% of these accidents involve severely or fatally injured occupants [1–3]. Not taken into account are accidents involving light sport aircraft (ultralights), skydivers, or paragliders; these are not considered aircraft but, rather, sports utilities in Germany and are therefore not covered by the laws governing aviation accident investigation, leading to a lack of reliable data [4].

The German Federal Bureau of Aircraft Accident Investigation (Bundesstelle für Flugunfalluntersuchung) (BFU) in Braunschweig, Germany, is responsible for accident investigation in compliance with the International Civil Aviation Organization Annex 13 with the therein-stated purpose of preventing further accidents and incidents. The BFU publishes annual reports containing data about the number of accidents and the number and severity of the injuries sustained classified by aircraft category [1].

The aim of this study was to derive values for the average number of severely injured persons (ANI), the average number of fatally injured persons (ANK), and the severity of the injuries sustained in German GA accidents in reference to the aircraft category. Moreover, probabilities for sustaining severe or fatal injuries were calculated.

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Material and Methods

The official annual reports of the BFU from 1993 to 2007 were used to gather data for this study [1]. These reports contain information regarding the aircraft category, the number of severely and fatally injured, and a short synopsis.

A 15-year period (1993 to 2007) was analyzed to improve validity and enhance data quality. Additionally, a database search was performed to identify all GA accidents [1] and to enable further detailed analysis. Subgrouping of accidents was performed using the official German aircraft registration criteria (see Table 1).

The definition of an accident was retrieved from the Federal Aviation Regulations‡:

> Aircraft accident means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

A severe injury [1] is classified as injury sustained in an accident leading to 1) hospitalization for more than 48 h within seven days after the accident; or 2) fractures, with the exception of minor fractures of fingers, toes, or nose; or 3) lacerations with severe bleeding or nerve, muscle, or tissue damage; or 4) injuries of internal organs; or 5) second- or third-degree burns of more than 5% of body surface; or 6) exposure to infectious material or harmful radiation.

A fatal injury is classified as injury sustained in an accident resulting in immediate death or death within 30 days of the accident. Accident analysis focused on the severity of the injuries sustained and the number of seriously or fatally injured persons.

1) The ANI value pertains only to accidents involving severe injuries and shows the ANI that can be expected in these cases. It is calculated by dividing the number of severely injured by the number of accidents involving severe injuries.

‡Data available at http://law.justia.com/us/cfr/title49/49-7.1.3.1.12.html [retrieved 21 September 2010].

Table 1 Subgrouping of accidents performed using official German aircraft registration criteria

Class	Description
Aircraft MTOM 2–5.7 tons	6 or more seats (e.g., 537 registered in 2007)
Aircraft with MTOM of less than 2 tons	2 to 4 seats (e.g., 6935 registered in 2007)
Helicopters	2 to 4 seats (e.g., 731 registered in 2007)
TMGs	2 seats (e.g., 2824 registered in 2007)
Gliders	1 to 2 seats (e.g,. 7769 registered in 2007)
Hot-air balloons	approx. 4 places (e.g., 1264 registered in 2007)

Table 2 Accidents between 1993–2007 by aircraft categories

Class	No. of accidents	Share, %
Airplanes with MTOM of 2–5.7 tons	182	3.5
Airplanes with MTOM of less than 2 tons		36.7
Helicopters	258	4.9
TMGs	569	10.8
Gliders	1930	36.7
Hot-air balloons	391	7.4

2) The ANK value pertains only to accidents involving fatal injuries and shows the ANK that can be expected in these cases. It is calculated by dividing the number of fatally injured by the number of accidents involving severe fatal injuries.

3) The probability of severe injury per accident (POS) value is the ratio of accidents with severely injured occupants divided by the total number of accidents in a given subgroup. It gives the percentage of accidents resulting in severe injuries.

4) The probability of fatal injury per accident (POF) value is the ratio of accidents with fatally injured occupants divided by the total number of accidents in a given subgroup. It gives the percentage of accidents resulting in fatal injuries.

For data management, Microsoft Excel® 2003 (Microsoft Corporation, Redmond, Washington) was used. Statistical analysis was performed using Statistika® (V6.0, StatSoft, GmbH, Hamburg, Germany). Figures were created using SPSS® (V16.0, SPSS, Inc., Chicago, Illinois). A $p < 0.05$ was considered significant.

Results

Data Acquisition

Between 1 January 1993 and 31 December 2007, a total of $n = 5,259$ GA accidents in Germany were identified and analyzed (Table 2). Of these, $n = 804$ accidents (15.3%) lead to severe and $n = 605$ accidents (11.5%) lead to fatal injuries. A total of $n = 1084$ occupants were severely injured, and $n = 1044$ occupants were fatally injured.

Aircraft Categories

The highest number of accidents was found for gliders ($n = 1930$; 36.7%) and aircraft with maximum takeoff mass (MTOM) of less than 2 tons ($n = 1929$; 36.7%), followed by touring motor gliders (TMGs) ($n = 569$; 10.8%), hot-air balloons ($n = 391$; 7.4%), helicopters ($n = 258$; 4.9%), and aircraft with MTOM of 2–5.7 tons ($n = 182$; 3.5%; Table 2).

Occupants' Injuries

The highest ANI was found in the category of aircraft with MTOM of 2–5.7 tons (ANI = 3.0), although with the lowest overall probability (POS = 5.5%; Figs. 1 and 2). Consequently, only one out

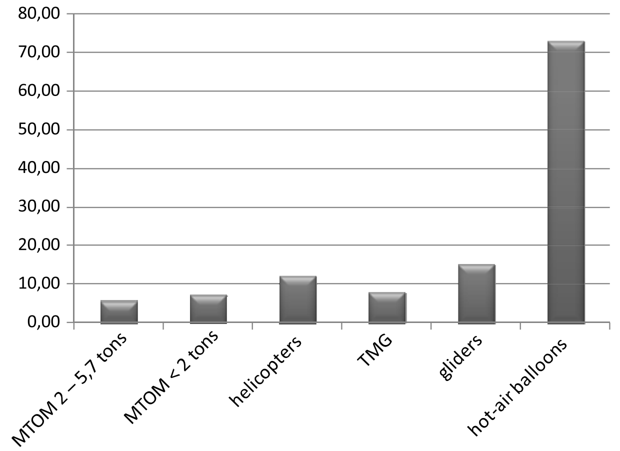

Fig. 2 POS percentage for the years 1993 to 2007. The aircraft category is provided on the *x* axis, whereas the *y* axis shows the POS percentage.

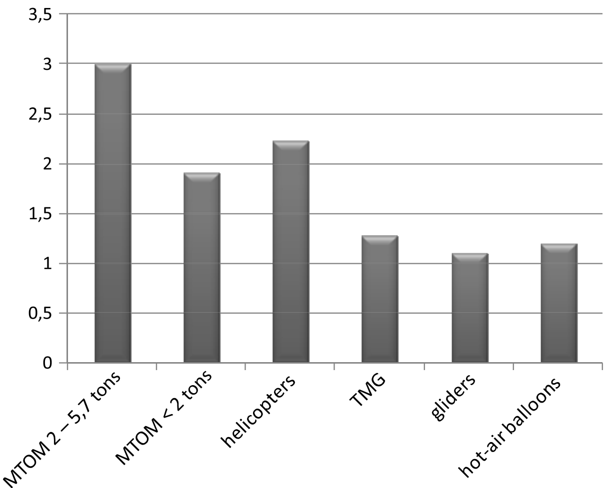

Fig. 1 ANI per accident for the years 1993 to 2007. The aircraft category is provided on the *x* axis, whereas the *y* axis shows the ANI.

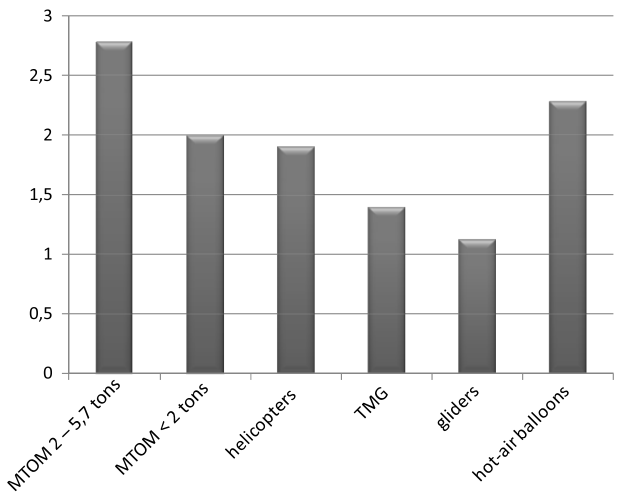

Fig. 3 ANK for the years 1993 to 2007. The aircraft category is provided on the *x* axis, whereas the *y* axis shows the ANK.

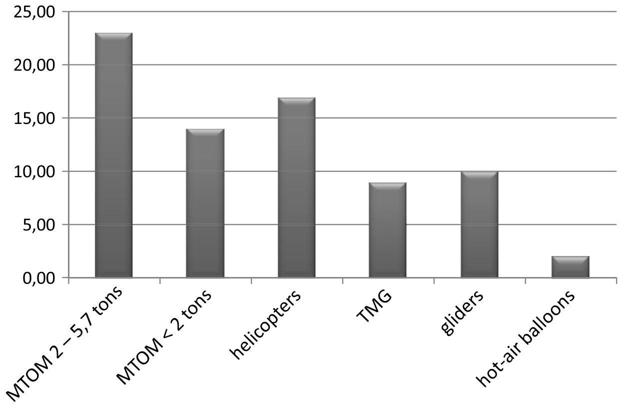

Fig. 4 POF percentage for the years 1993 to 2007. The aircraft category is provided on the *x* axis, whereas the *y* axis shows the POF percentage.

of 18 accidents resulted in occupants sustaining severe injuries. The lowest ANI was found in the category of gliders (ANI = 1.1) with a probability (POS) of 15.5% (an average of 1.1 injured occupants in every seventh accident; Fig. 2). For hot-air balloons, an ANI of 1.2 was found with a POS of 72.9% (Figs. 1 and 2).

The highest ANK was also found in the category of aircraft with MTOM of 2–5.7 tons (ANK = 2.8), with a POF of 23.1%, followed by hot-air balloons (ANK = 2.29), with a POF of 1.8% (Figs. 3 and 4).

The lowest ANK was found in the category of gliders (ANK = 1.13), with a POF of 10.0%. The highest POF was found for aircraft with MTOM of 2–5.7 tons (POF = 23.1%), followed by helicopters (POF = 17.1%), with an ANK of 1.9 (Fig. 4).

Relative Risk

Since both subgroups of aircraft with MTOM of less than 2 tons and gliders were involved in the majority of GA accidents (73.4%), they were used as reference groups for the assessment of relative risks (Tables 3 and 4). In reference to so-called sports aircraft with MTOM of less than 2 tons, which were involved in 37% of GA accidents, the relative risk for sustaining severe injuries is 2.29 (ANI) for gliders and 10.04 (ANI) for hot-air balloons. On the other hand, the relative risk for sustaining fatal injuries in aircraft with MTOM of 2–5.7 tons was 2.31 times higher than for gliders (Tables 3 and 4).

Table 3 Relative risk of sustaining a severe injury by aircraft categories

Class	In relation to airplanes with MTOM of less than 2 tons	In relation to gliders
Airplanes with MTOM of 2–5.7 tons	0.76	0.36
Airplanes with MTOM < 2 tons	1.00	0.48
Helicopters	1.66	0.79
TMGs	1.09	0.52
Gliders	2.09	1.00
Hot-air balloons	10.04	4.80

Table 4 Relative risk of sustaining a fatal injury, divided by aircraft categories

Class	In relation to airplanes with MTOM of less than 2 tons	In relation to gliders
Airplanes with MTOM of 2–5.7 tons	1.65	2.31
Airplanes with MTOM < 2 tons	1.00	1.39
Helicopters	1.22	1.71
TMGs	0.63	0.88
Gliders	0.72	1.00
Hot-air balloons	0.13	0.18

Conclusions

So far, a fairly adequate risk assessment is possible in commercial aviation due to the extensive data being recorded. As a result, risk factors are constantly being identified, and revised procedures and methods are being applied to further minimize mishap potential in the already very safe airline environment. For the less regulated and supervised conglomerate of GA, this systematic approach has not yet been feasible due to a lack of both denominator data and standardized approaches to accident analysis and classification.

Since neither the total number of hours, the total distances flown, nor the number of transported passengers is recorded in GA, the development of accident statistics is complicated, if not entirely impossible [5]. Although flight time is recorded in the aircraft logbook, these data are not summarized or available in a global database. The establishment of enhanced databases that include more variables (as found in commercial aviation) could drastically improve statistical accident analysis in GA. While an exact specification of injuries or fatalities per hours flown and the subsequent development of relative values is not possible, we were able to calculate ANI and ANK and the associated probabilities for past accidents that might well be expected should an accident occur (conditional probabilities). While being far from all encompassing, these data are the first attempt in a process to better quantify risks found in GA and can be supportive in both a further approach to understanding and improving flight safety as well as acute disaster management. Nevertheless, the present lack of common denominator data, specifically the number of flights and the hours flown, renders further accident analysis and comparisons for GA highly suggestive and needs to be clearly addressed. One simple solution might be the official recording of the yearly hours and numbers of takeoffs (e.g., aircraft logbook). These data could be easily obtainable during the mandatory yearly airworthiness inspections. Once valid denominator data are available, further calculations are possible and may help to improve flight safety.

Statistically, three out of four aviation accidents (73.4%) involve gliders or small aircraft (MTOM of less than 2 tons). Our results show that the ANI or ANK positively correlate with airplane size and capacity (Figs. 2–4). Although seemingly trivial, different factors can be of relevance for this result. Considering the average number of seats in the different aircraft categories, it has to be taken into account that this number also varies greatly with increasing aircraft size. Moreover, aeronautical factors can have an impact on the correlation.

While emergency offairport landings can often be performed without harm in smaller sports aircraft, this is simply not possible in larger piston aircraft or jets. Another aspect is the usually commercial use of larger GA airplanes, resulting in a higher workload and number of occupants. The reasons for a subsequent decrease of the injury risks are hard to identify without more detailed information about safety standards, crew qualification and training, nature of the flight, environmental factors, etc. [6,7].

Since, in contrast to commercial aviation, no declaration about the average number of occupants can be made for GA flights, a worst-case scenario has to be taken into account for disaster management planning. A comparable number of accidents occurred in the aircraft categories of gliders and airplanes with MTOM of less than 2.0 tons, in which it is generally accepted that these are most often recreationally used and flown by private pilots. The higher risk for severe injury in gliders can most likely be attributed to the generally performed offairport landings in unknown terrain with all the associated risk factors (59.4% landing accidents [8]). The small ANI and ANK can be attributed to the high proportion of single-seat gliders. Moreover, comparatively lower airspeeds and, therefore, reduced impact energy and the absence of fire hazards can also contribute to the reduced risk of fatal injury.

The high risk for severe injuries in hot-air balloon mishaps has to be noted. A study of United States hot-air balloon accidents from 1964–1995 by Cowl et al. showed impact with the ground or power lines as the most likely cause for accidents and as a predictor for mortality rates [9]. Frankenfield and Baker found similar results in an analysis of data from 1984 and 1988 [10]. New measures to improve passenger safety (e.g., new approaches to gondola engineering) have to be explored.

The inhomogeneous group of GA, which summarizes anyone from highly trained corporate pilots to low-time recreational flyers, shows a much less differentiated and, unfortunately, worse accident record than commercial aviation. Considering the rareness and the potentially high number of casualties in GA accidents, the process of information gathering is especially crucial for an adequate disaster response. Exact knowledge about the location of the crash, the airplane model and size, or the number and type of engines can be pivotal in choosing the right approach. Additional information about the course of the accident, the number of casualties, and the structural damage at the crash site can further improve the disaster management on the scene.

A study by O'Hare et al. showed that environmental factors (e.g., weather and terrain at the crash site) and operational variables (number of pilots, training, etc.) have a higher impact on outcome in regard to injuries in GA accidents than airplane performance or pilot demographics (age, sex, experience, etc.) [11]. The authors identified both the terrain at the crash site and the occurrence of fire as the biggest risk factors. It can still be assumed that the demand on pilots in regard to training and experience increases with airplane complexity, which most likely has a positive effect on accident statistics [12,13].

Summarized, the number of injuries and fatalities in GA aircraft accidents may vary significantly, but it is below three in approximately 75% of the cases. Therefore, severity is comparable to road traffic accidents [14]. On the other side, injury patterns [3,8,15–17] and associated risk factors (e.g., fire) [9,18] differ significantly. Therefore, the data of the present study may also have impact on disaster management in the field after GA aircraft accidents.

We intentionally chose a 15-year period to improve validity and enhance data quality. After the implementation of the Joint Aviation Regulations for Flight Crew Licensing and Joint Aviation Regulations for Operations in the year 2003, changes in aircraft licensing came into effect that may slightly influence the study results (light sport aircraft and TMG), specifically because some aircraft can now be licensed in categories where accidents are not necessarily investigated (see next). Since aviation mishaps involving light sport aircraft, hang gliders, or parachutes were not covered by the German laws regarding aviation mishap investigation during the study period, they are not included in the database, and no reliable data are available. As of 2010, no other database covering these accidents exists in Germany. Therefore, it was not possible to compare GA mishaps with these fairly young aircraft or air sports categories. Establishing a suitable accident database in combination with subsequent accident investigation could help further accident prevention and overall flight safety in these aircraft categories.

Moreover, due to the relatively scarce data on GA accidents, only a retrospective analysis based on short synopsis reports was possible. While including numbers of severely and fatally injured persons, no further mention of injury patterns is made. Other national databases, like the German Trauma Registry of the German Society for Trauma Surgery (DGU), also do not cover these accidents. Availability of more detailed data would be crucial for a better analysis of injury patterns and the subsequent development of accident management plans.

References

[1] "Jahresberichte," Bundesstelle für Flugunfalluntersuchung, Braunschweig, Germany, http://www.bfu-web.de/cln_005/nn_223970/DE/Publikationen/Statistiken/statistiken__node.html?__nnn=true [retrieved 21 Sept. 2010].

[2] Dambier, M., Glaser, E., Neuhaus, C., and Hinkelbein, J., "Unfallanalysen in der Allgemeinen Luftfahrt: Eine Betrachtung International Publizierter Flugunfallanalysen in der Allgemeinen Luftfahrt," *Flugmed Tropenmed Reisemed*, Vol. 15, No. 2, 2008, pp. 68–71.

[3] Dambier, M., and Hinkelbein, J., "Analysis of 2004 German General Aviation Aircraft Accidents According to the HFACS Model," *Air Medical Journal*, Vol. 25, No. 6, 2006, pp. 265–269. doi:10.1016/j.amj.2006.03.003

[4] "Gesetz über die Untersuchung von Unfällen und Störungen bei dem Betrieb Ziviler Luftfahrzeuge (Flugunfall-Untersuchungs-Gesetz-FlUUG)," Bundesministerium der Justiz Bundesgesetzblatt, I S.2470, 1998.

[5] Hinkelbein, J., Neuhaus, C., Schwalbe, M., and Dambier, M., "Significant Lack of Data in Aviation Accident Analysis," *Aviation, Space, and Environmental Medicine*, Vol. 88, No. 1, 2009, p. 77.

[6] Pauley, K., O'Hare, D., and Wiggins, M., "Risk Tolerance and Pilot Involvement in Hazardous Events and Flight into Adverse Weather," *Journal of Safety Research*, Vol. 39, No. 4, 2008, pp. 403–411. doi:10.1016/j.jsr.2008.05.009

[7] Hinkelbein, J., Dambier, M., Glaser, E., and Landgraf, H., "Medical Incapacitation im Cockpit: Inzidenz, Ursachen und Folgen," *Flugmed Tropenmed Reisemed*, Vol. 15, No. 1, 2008, pp. 14–19.

[8] van Doorn, R. R., and de Voogt, A. J., "Glider Accidents: An Analysis of 143 Cases, 2001–2005," *Aviation, Space, and Environmental Medicine*, Vol. 78, No. 1, 2007, pp. 26–28.

[9] Cowl, C. T., Jones, M. P., Lynch, C. F., Sprince, N. L., Zwerling, C., and Fuortes, L. J., "Factors Associated with Fatalities and Injuries from Hot-Air Balloon Crashes," *JAMA*, Vol. 279, No. 13, 1998, pp. 1011–1014. doi:10.1001/jama.279.13.1011

[10] Frankenfield, D. L., and Baker, S. P., "Epidemiology of Hot-Air Balloon Crashes in the U. S., 1984–88," *Aviation, Space, and Environmental Medicine*, Vol. 65, No. 1, 1994, pp. 3–6.

[11] O'Hare, D., Chalmers, D., and Schuffham, P., "Case-Control Study of Risk Factors for Fatal and Non-Fatal Injury in Crashes of Civil Aircraft," *Aviation, Space, and Environmental Medicine*, Vol. 74, No. 10, 2003, pp. 1061–1066.

[12] Li, G., Baker, S. P., Grabowski, J. G., Qiang, Y., McCarthy, M. L., and Rebok, G. W., "Age, Flight Experience, and Risk of Crash Involvement in a Cohort of Professional Pilots," *American Journal of Epidemiology*, Vol. 157, No. 10, 2003, pp. 874–880. doi:10.1093/aje/kwg071

[13] Li, G., and Baker, S. P., "Correlates of Pilot Fatality in General Aviation Crashes," *Aviation, Space, and Environmental Medicine*, Vol. 70, No. 4, 1999, pp. 305–309.

[14] Eid, H. O., and Abu-Zidan, F. M., "Biomechanics of Road Traffic Collision Injuries: A Clinician's Perspective," *Singapore Medical Journal*, Vol. 48, No. 7, 2007, pp. 693–700.

[15] Ast, F., Kernbach-Wighton, G., Kampmann, H., Koops, E., Püschel, K., Tröger, H., and Kleemann, W., "Fatal Aviation Accidents in Lower Saxony from 1979 to 1996," *Forensic Science International*, Vol. 119, No. 1, 2001, pp. 68–71. doi:10.1016/S0379-0738(00)00398-4

[16] Chalmers, D. J., O'Hare, D. P., and McBride, D. I., "The Incidence, Nature, and Severity of Injuries in New Zealand Civil Aviation," *Aviation, Space, and Environmental Medicine*, Vol. 71, No. 4, 2000, pp. 388–395.

[17] Shkrum, M., Hurlbut, D., and Young, J., "Fatal Light Aircraft Accidents in Ontario: A Five Year Study," *Journal of Forensic Sciences*, Vol. 41, No. 2, 1996, pp. 252–263.

[18] Chaturvedi, A. K., and Sanders, D. C., "Aircraft Fires, Smoke Toxicity, and Survival," *Aviation, Space, and Environmental Medicine*, Vol. 67, No. 3, 1996, pp. 275–278.